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THE ORIGIN OF GYPSUM IN ALBERTA DEPOSITS

BY

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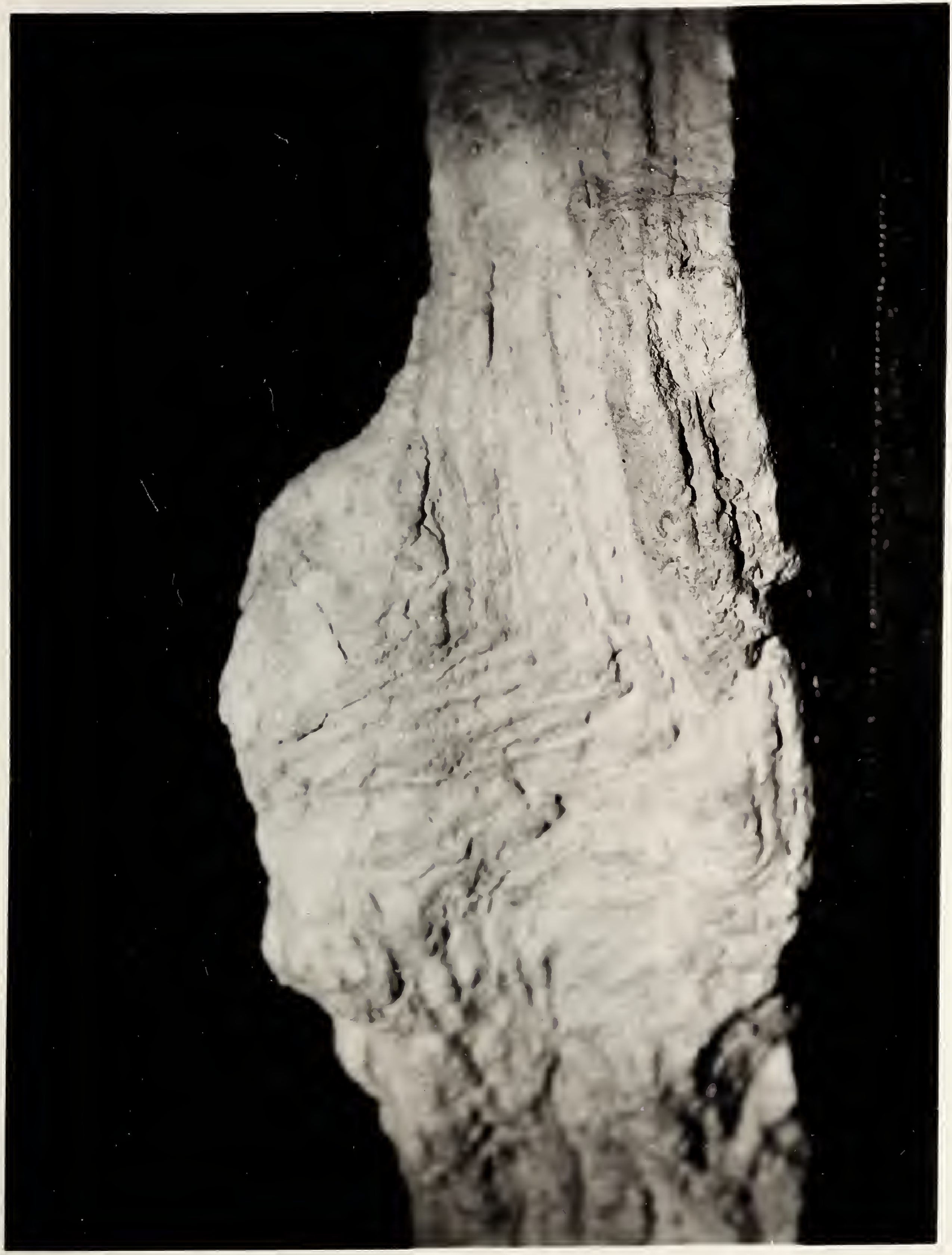
PHOTOGRAPH SHOWING FOLDING IN GYPSUM

FROM JASPER PARK.



THE ORIGIN OF GYPSUM DEPOSITS IN ALBERTA

by

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Edmonton, Alberta. April, 1935.

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CHAPTER I

INTRODUCTION

General Statement

The problem of the origin of gypsum has long been considered and many varied hypotheses have been introduced to explain its mode of origin. Some of these theories are purely theoretical, others are based on field observations and determinations. Even in the latter case strong tendencies are sometimes shown to use subordinate features of a deposit to substantiate a theory.

Much of the recent work on gypsum has been carried on to determine the economic possibilities of different gypsum deposits. This work, though it has offered little explanation for the origin of gypsum deposits, has been valuable in outlining its modes of occurrence and is the basis for future comprehensive study. With the increasing knowledge and more detailed study of the known deposits accepted theories, in some instances, are broken down upon their application to more specific findings.

With these tendencies well in mind the writer wishes to present a study of the origin of gypsum with special reference to the Alberta deposits. Since gypsum deposits are found in other parts of Canada a general discussion of the Canadian gypsum deposits will be presented and similar depositional features will

be noted.

The mineral gypsum has proven itself to be of relatively great value among Canada's non-metallic minerals. The development of the economic importance of gypsum in Canada can be truly represented by statistical figures. Two short appendices dealing, first, with the economic importance of gypsum from a statistical viewpoint and, second, the historical development of the industry have been included.

To comprehensibly discuss gypsum deposits general theories pertaining to their origins and modes of occurrence will first be presented.

Gypsum itself is a hydrated, non-metallic mineral having in the pure condition the formula $CaSO_4 . 2H_2O$. The anhydrous form corresponding to the formula $CaSO_4$ is known as anhydrite and occurs as a common associate of gypsum. In percentages of weight gypsum corresponds to the following composition*:

Gypsum	Lime Sulphate	Lime (CaO)	32.5%	79.1%
		Sulphur trioxide	46.6%	
	Water			20.9%

Gypsum occurs in a variety of forms. The more important of these are selenite, satin spar or fibrous gypsum, rock gypsum and gypsite. For a description of these types see page 31 .

Gypsum can be distinguished by its physical properties. It has a hardness of 2 (Mohs scale of hardness) specific gravity

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*Cole, L. H.: Mines Branch, Rept. No. 245, 1913, p. 5.

of 2.3 and a white streak. Its lustre varies from pearly to subvitreous, and its color though usually white may be gray, fleshred, yellow or blue. The variety selenite may be transparent; rock gypsum is usually opaque.

Acknowledgments.

The writer is greatly indebted for the help and suggestions given him during the preparation of this thesis. To Dr. J. A. Allan who suggested this problem and under whom this thesis has been prepared, I wish to convey my thanks for his advice and criticisms. I wish also to express my thanks to Dr. R. L. Rutherford for his criticisms and to Dr. P. S. Warren for his helpful suggestions. To Dr. A. E. Cameron I am indebted for his help in connection with the Peace River deposits. Through the courtesy of Mr. William Calder, Director of the Petroleum Branch of the Department of Lands and Mines, Province of Alberta, I was able to obtain data on the occurrences of gypsum in Alberta wells. The receipt of the material so obtained is gratefully acknowledged.

The writer has relied upon the library facilities of the University of Alberta and upon the private libraries of Dr. Allan, Dr. Rutherford, and Dr. Warren. For the conveniences afforded him in this connection the author wishes to express his gratitude.

CHAPTER II

THE ORIGIN OF GYPSUM.

General Theories As To Origin.

Much has been written with reference to the origin of gypsum deposits and controversies have naturally arisen. Chemists and geochemists favor the formation of gypsum deposits through chemical means and suggest it as being the major factor in the formation of gypsum. Geologists favor the theory that the major gypsum deposits are formed by primary deposition from solutions or as an alteration production from the hydration of anhydrite. Much can and has been said for both sides. It is a fact, however, that no single theory gives an adequate explanation of the conditions as found in the field.

I. DEPOSITION FROM SOLUTIONS

(1) Deposition from Sea Waters.

It is generally considered by many geologists that most of the important gypsum deposits that have been examined were produced by deposition from sea water. The theory has been based upon the "salt-pan" hypothesis. Briefly, the "salt-pan" hypothesis postulates a basin containing sea-water that is partially or wholly cut off from the ocean. The concentration of the trapped saline waters due to evaporation has led to the ultimate deposition of

the calcium sulphate salts. The mere fact that gypsum is found as bedded units seems to substantiate such a viewpoint. The common occurrence of gypsum interbedded with shales, sandstones and limestones seems also to point towards a sedimentary deposition. A modern example of the deposition of gypsum under "salt-pan" conditions is found in some basins at the eastern side of the Caspian Sea. Even this typical example brings out problems which cannot be passed over lightly.

One such problem is the deposition of numerous organisms that have been drawn from the Caspian Sea in the salt-basins. These organisms are being laid down with the sulphate deposits which are being formed at present. Gypsum deposits show a characteristic lack of fossil remains which R. W. Stone* attributes to the concentration of the saline waters. This does not explain the conditions as found in the Caspian Sea basins. A more satisfactory and yet at the same time a more theoretical explanation postulates a secondary basin in which the gypsum is deposited. In this case the marine organisms are deposited in the primary basin, the concentrated solutions only being carried to the secondary or main depositional basin. An adequate explanation for general purposes relies on the fact that the concentration of the saline solutions, even before gypsum starts to form, is too great to permit of any life. This reasoning is based on a modification of the Oschenius*

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*Stone, R. W.: U. S. G. S. Bull. 697, 1920, p. 22.

*(Branson, E.B.: Bull. Geol. Soc. Am., Vol 26, 1914, p. 232.)

bar hypothesis.

Another major problem confronting the adherents of the depositional theory is involved in the great thicknesses of some deposits. Often gypsum deposits show thicknesses from 40 to 50 feet and in some instances reach as much as 100 feet or more. The problem connected with this lies in the fact that ordinary sea water contains only 1.7488 parts per thousand calcium sulphate in solution. Since salt precipitates rapidly as soon as 1.4 parts of gypsum has been deposited, only 1.4 parts per thousand is available for deposition in pure gypsum deposits. Gypsum does not precipitate until concentration to one-fifth of the former volume of sea water has taken place. With the additional factor that .7 feet of gypsum is precipitated from 1,000 feet of normal sea water it can be determined that 11,500 feet of saline water saturated with respect to calcium sulphate will be necessary to precipitate a 40 foot bed of gypsum. Such a depth is prohibitive for any continental depressions.*

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*Branson, E. B.: Bull. Geol. Soc. Am., Vol. 26, 1914, p. 232.)

The occurrence of thick gypsum deposits has been explained in several different ways. The bar theory of Oschenius serves as a partial explanation. The addition of a new supply of saline water at a rate dependent upon the rate of evaporation in the basin would at the same time supply the basin with more calcium sulphate. Precipitation of this sulphate would occur when the sea water has been suitably concentrated. The concentrated solutions now hold

salt and if they become concentrated to one tenth of their original volume they will deposit salt with the gypsum. A pure 40-foot bed of gypsum would necessitate a 5,400-foot basin to keep the overlying solutions from depositing salt with the gypsum.

A modification of the Oschenius bar theory was advanced by E. B. Branson* in 1914 as an explanation of thick gypsum deposits. According to this theory the receiving basins are supplied with highly concentrated solutions. This method tends towards a speeding up of the depositional processes but as in the previous case still retains the necessity of a body of water to keep the salt in solution.

Both of these theories, then, postulate rather large depth for continental basins and give no adequate explanation of the numerous salt-free thick gypsum occurrences. It seems unreasonable to think that the processes of deposition could have been interrupted in so many instances just previous to the deposition period of salt.

The limited lateral extent of thick gypsum deposits within thinner but more wide-spread deposits has lead to the theory of concentration in localized depressions. A localized area containing a 40 or 50-foot gypsum bed might thin laterally to widespread gypsum deposits with a thickness of 10 feet or less. Branson* considers from his investigation that for every 100 square miles of

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*Branson, E. B.: Bull. Geol. Soc. Am., Vol. 26, 1915, p. 235.

*Branson, E. B.: Bull. Geol. Soc. Am., Vol. 26, 1915, p. 233.

40 to 50-foot gypsum beds that there is 2,000 square miles of 10-foot beds. Such circumstances have led to the belief that the gypsum has been shifted by wave and current action. Accumulation of gypsum would occur in any minor depression, the main depositional basin losing gypsum to the lower depressions.

In relation to this problem another factor must be considered. The present attitude of a gypsum deposit may be quite changed from its original form. Folding and doming might have altered the original deposit; for example, folding would probably tend towards a thinning of the deposits on the limbs and a thickening on the crests and troughs, and doming would tend towards a thinning on the crest. Field information on this subject is, however, unobtainable and no definite conclusions can be drawn.

The absence of salt above many thick gypsum deposits presents a problem to the "salt-pan" theorists. Certain factors believed to be capable of interrupting deposition have been advanced in support of the theory. Some of these factors are freshening from inflowing rivers, increase in rainfall, or a filling of the supply basin (with sediments), giving a larger overflow and decrease in salinity due to a decrease in evaporization.

One or more of these phenomena might enter into the process and quite conceivably arrest deposition. At least two of these, however, would be likely to leave some trace of their action. Rivers of sufficient size to prevent the deposition of salt would carry sedimentary material and deposit it along with the gypsum.

And, also, any increase in rainfall sufficient to overcome evaporation would cause a deposit of mud and sand in the gypsum basin. The marked purity of certain gypsum deposits does not allow of such conditions.

Considering the deposition of gypsum and salt to be consanguineous, there are three points at which deposition may be interrupted. The first of these would be before all the gypsum had been deposited. Since salt does not deposit until most of the gypsum has precipitated no salt would be expected above the gypsum, but at the same time the thickness of the gypsum deposit could not be considered the maximum possible thickness for the deposit. Such conditions would have to be applied to the thickest gypsum deposits.

The second point at which deposition might be stopped would be just previous to the deposition of salt. This represents a very limited period and cannot be relied upon as a true representation of conditions as they existed.

Deposition might also continue till some or all the salt had been deposited above the gypsum. The absence of salt in this case could then only be explained by a subsequent removal of salt. The most obvious method for its removal would be by re-solution. This might be caused by river water or by a transgression of the sea water. River action, although it might be very effective in low topography, would be likely to leave some remnants of the

salt deposit. A transgression of the sea would be the more likely and at the same time quite feasible method for the complete removal of the salt. The presence of marine deposits overlying the gypsum would in itself substantiate such a viewpoint. The presence of thin unconsolidated sediments over the salt deposits would not interfere with the action since these would be eroded by the advancing sea or the salt would be removed by leaching.

The absence of indigenous sedimentary impurities in gypsum beds is at least partially explained by the modified bar hypothesis of Branson. No streams are considered to empty directly into the main depositional basin. The main sedimentary material would be deposited in the secondary basins. Any sediments carried over might easily become segregated by depositional forces away from the main gypsum depositing region.

The purity of gypsum is also enhanced by the relative speed with which gypsum deposition takes place once the process has started. This would leave but a short interval in which sediments could be deposited with the gypsum and as a consequence increase the purity of the gypsum.

The absence or rarity of other salts within gypsum deposits can be explained on a physical-chemical basis. The only other salt that is precipitated from solution under conditions of concentration suitable for the deposition of gypsum is calcium carbonate. The "lime carbonate problem" has been fully discussed by F. A. Wilder*. The scarcity of salts such as glauberite and carnallite

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*Wilder, A. F: Bull. Geol. Soc. Am., Vol. 32, 1921, p. 385.

in sea water might in part explain their absence or lack of detection in gypsum deposits. The fact also that they are precipitated from solution after halite makes it even less likely that they should be present. Their ready solubility would likewise place them as substances easily removed by the subsequent actions of sea waters, river waters or ground waters.

(2) Deposition from Rivers.

Rivers are known to be capable of depositing gypsum. Their importance, however, is very minor. No deposits even approaching economic importance are known to have been formed by them. Mechanical transportation of gypsum by a river that has passed over a gypsum deposit produces a very impure deposit. Rivers may also transport ionized $CaSO_4$ in solution. In this case deposition will only occur when the river water is evaporated. The amount of $CaSO_4$ in the average river water is very small; 1 part in 100,000 so that even under the special conditions favorable to deposition no great deposit could be expected.

(3) Deposition in Veins.

Vein deposits of gypsum in all probabilities represent secondary deposits. They consist of gypsum fillings in cracks and fissures. Their frequent association with gypsum-bearing rocks has lead to the belief in their secondary origin. Some of the gypsum is thought to have been dissolved and re-

deposited in the fissures and cracks.

Fibrous gypsum is the common form in vein deposits. These deposits are of no economic importance. The type, however, will be of special importance since the McMurray deposits show venal depositions.

II DEPOSITS FORMED BY ALTERATION PROCESSES.

(1) Deposits formed by Acid Sulphate Solutions.

The major section of the remaining gypsum deposits falls into one group; that is, those formed by the chemical alteration of previously formed deposits. Sulphuric acid, acting on limestone, might produce gypsum according to the equation:

$$H_2SO_4 + CaCO_3 \longrightarrow CaSO_4 + CO_2 + H_2O$$

$$2H_2O + CaSO_4 \longrightarrow CaSO_4\ 2H_2O$$

The sulphuric acid for such a reaction may be obtained by the oxidation of hydrogen sulphide of sulphur springs and volcanoes, or by the decomposition of pyrite and subsequent oxidation and hydration of the sulphur dioxide so obtained.

Although deposits of this type are generally considered to be of little or no economic importance Dana* considers many of the New York deposits to have been formed by the action of sulphuric acid from sulphur springs. The lensing of gypsum deposits in limestone and the presence of layers of shale passing unaltered through irregular gypsum pockets in the limestone seems to be the

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*Dana, J. D.: Manual of Geol. 4th Ed., 1895, p. 554.

basis for the reasoning.

W. A. Bell* has carried out a comprehensive discussion with regard to alteration of limestones by sulphuric acid. He states: "There are several features of the sulphate deposits that make this alteration hypothesis untenable; e. g.,(1) the widespread occurrence both laterally and vertically of thick gypsum and anhydrite beds; (2) the general absence or rarity of contemporaneous volcanism in most of the gypsum districts; (3) the absence or rarity of transition deposits of limestone and calcium sulphate with undoubted replacement phenomena; (4) the evidence in favour of original widespread anhydrite rather than gypsum deposition."

With such factors pointing controversally towards the theory of limestone alteration Bell concludes that the "limestone alteration hypothesis for the origin of the great bulk of Nova Scotian gypsum and anhydrite must be discarded as inadequate and contrary to the facts."

The conditions as described by Bell may well apply in general to gypsum deposits considered as formed by chemical alteration. This would not apply to the minor occurrences near fumaroles and in vein deposits with hematite.

(2) Deposits formed from Anhydrite.

Gypsum derived from anhydrite must also be considered as an alteration product. In this case the chemistry involved is

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*Bell, W. A.: G. S. C. Mem. 155, Horten-Windsor District, Nova Scotia, 1929, p. 82.

the hydration of anhydrous calcium sulphate according to the equation: $CaSO_4 + 2H_2O \longrightarrow CaSO_4 . 2H_4O$.

In a section of this chapter the genetic relationships of gypsum and anhydrite will be discussed. The primary or secondary nature of gypsum or of anhydrite is at this point the important problem. The present general trend of thought places anhydrite as the more important form of primary deposition, gypsum being considered as a secondary formation from the subsequent hydration of anhydrite. Circulating meteoric water is considered to be the main factor in hydration. Cole* and Rogers* list several reasons for this theory:

"(1) The concentration of the sea water with respect to sodium chloride was in all probability sufficiently high and the temperature of the water favourable for the deposition of the calcium sulphate as anhydrite rather than gypsum.

"(2) The increasing prevalence of anhydrite in many quarries as they are opened up to depth.

"(3) The almost universal encountering of anhydrite below a certain depth in the many drill holes put down in the Maritimes in which calcium sulphate was present.

"(4) The many evidences in the rock excavated in the quarries of samples where anhydrite is partly altered to gypsum.

"(5) Where anhydrite lenses occur as irregular masses in gypsum,

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*Cole, L. H. and Rogers, A. F.: Dept. of Mines, Ottawa, Rept. No. 732, 1933, p. 7

the evidence indicates that these masses are remnants of the original anhydrite which have not been completely hydrated to gypsum.

"(6) The minute crystals of anhydrite in the salt crystal mass at the Malagash salt mine indicate that at the time of salt deposition the salinity of the sea and the temperature were favourable for anhydrite deposition."

If then these reasons can be taken as adequate, gypsum takes the place of an incidental development due to external agents of alteration.

Conditions as they are found in numerous deposits will not allow the sole use of this theory as an explanation of origin. An example of this is to be found in the Gypsumville deposits of Manitoba. R. C. Wallace* describes the sequence of deposition, gypsum - anhydrite - gypsum. He points out that the most satisfactory explanation for such a depositional sequence is that the gypsum lying below the anhydrite is of primary origin. The gypsum above the anhydrite, however, lends itself to the theory that it is of secondary origin. (See ref.)

Brownell* explains this problem differently. The gypsum beds lying above and below the anhydrite are considered to have been derived from anhydrite. Glacial action is thought to have removed

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*Wallace, R. C.: Gypsum and Anhydrite in Genetic Relationship, Geol. Mag. 1914, p. 271-276.

*Brownell, G. M.: The Amaranth Gypsum Deposit, Trans. C. I. M. & M. 1931, p. 292.

the overlying strata and brought the anhydrite deposits to the surface. Alteration of the anhydrite by the action of ground water then took place. Due to the closeness of the deposit to the surface the ground water is considered to have acted at the top and bottom of the anhydrite bed to form gypsum in both positions. This explanation shows the strong tendency at present times to consider gypsum deposits as secondary. In view of this tendency special note will be made on the theory as to its possible application to the origin of Alberta deposits.

III. AEOLIAN DEPOSITS

One further type of gypsum deposit, though it has been given little consideration up to the present time, is of importance in the discussion of Alberta deposits. This type may be called Aeolian deposits; that is, deposits of gypsum accumulated by wind action. Loose gypsum when acted on by wind may be blown and moved. Due to differences in sizes of the grain particles and difference in specific gravity the wind action will function as a separating force. The gypsum will be separated from impurities and will be accumulated to form lens-like masses. Such lens-like masses are to be found in the Jasper Park deposits* and these lenses may well be designated as deposits of Aeolian origin.

It might be well to note at this point that wind action capable of producing such deposits would be subject to certain

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*Allan, John A. Trans. C.I.M.M., 1933, p. 15.

restrictions. The action would be preferably in one direction rather than in alternating directions. The more constant the veolocity of the wind at all times the greater would be the differential action of such a force. Since water action would have the effect of remixing the gypsum with sedimentary material the formation of Aeolian deposits would best take place under conditions of aridity.

IV. CONCLUSIONS.

One definite conclusion may be drawn from the discussion of the possible modes of origin of gypsum. No one well defined theory has proved to be adequate in explaining the origin of gypsum. In applying any one of these theories, in an effort to determine the origin of a deposit, care must be exercised. That theory which gives the simplest explanation and the truest interpretation of the conditions as they occur in the field should be the theory to represent the mode of origin for the deposit. The presence of primary gypsum, secondary gypsum and venal depositions within one deposit is quite possible and each type will necessitate a separate interpretation.

Genetic Relationship of Gypsum and Anhydrite.

Gypsum and anhydrite show a close relationship in formational conditions. Anhydrite has been deposited under conditions similar to the deposition of gypsum but certain physical and chemical agents have come into force to deposit the $CaSO_4$ in the hydrous form, gypsum, or the anhydrous form, anhydrite. A change of such physical and chemical conditions would have the effect of changing a gypsum deposition to an anhydrite deposition or vice versa.

The problem of the relationship existing between these two forms is best presented in deposits containing both gypsum and anhydrite but is not confined to this type of deposit. Deposits containing gypsum alone or deposits containing anhydrite alone which show similar deposition features must be explained on the same basis. Anhydrite appears less frequently in deposits of recent formation and represents an additional problem. These problems have been dealt with by Wallace* in his paper on gypsum and anhydrite in genetic relationship. Experimental work has been carried on by the United States Bureau of Mines with regard to the stability relationships of gypsum and anhydrite.*

The deposition of gypsum or anhydrite as mineralogical units seems to depend primarily on the factors of temperature and pressure. These factors show possibilities of variation and tend to modify or obliterate other depositional factors. The temperature at which a

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*Wallace, R. C.: Geological Mag., 1914, pp. 271-276.

*Farnsworth, M.: U. S. Bur. Mines Rept., Ser. No. 2654, 1924.

deposition of gypsum will change to a deposition of anhydrite varies from 60° C. in the presence of water, to 30° C. in the presence of a saturated brine solution. The stability relationships of gypsum, anhydrite and the hemi-hydrate as investigated by Van't Hoff and his co-workers is briefly tabulated below:*

"Natural anhydrite transforms into gypsum:-

(a) At 30° C. in presence of a saturated solution of NaCl.
(b) At 66° C. in presence of water.

"Soluble anhydrite transforms into gypsum:-

(a) At 65° C. in presence of a saturated solution of NaCl.
(b) At 89° C. in presence of water.

"Half-hydrate transforms into gypsum:-

(a) At 11° C. in presence of a saturated solution of magnesium chloride, $MgCl_2$.
(b) At 76° C. in presence of a saturated solution of NaCl.
(c) At 101.5°C. under atmospheric pressure.
(d) At 107° C. in presence of water. "

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*Wallace, R. C.: Geol. Mag. 1914, p. 272.

Experiments carried out by the U. S. Bureau of Mines* have given us additional information on pressure effects. In pressure bombs with water, anhydrite was found to remain unchanged at a temperature of 210° C. and a pressure of 19 atmospheres. Gypsum, treated in the same manner changed over to anhydrite at a temperature of about 160° C.

*(Bowles, O. and Farnsworth, M.: Ec. Geol., Vol.20, 1925, p. 74)

From such experimental data certain conclusions may be drawn. Under conditions of high temperature accompanied by pressure, anhydrite is the stable form, but from the standpoint of volume relationships, gypsum is the more stable form under conditions of pressure. This is due to the fact that while 1,000 grams of gypsum would occupy 431 cc. the water and anhydrite derived from this gypsum would occupy a volume of 476 cc., an increase of 45 cc. The common occurrence of anhydrite below gypsum horizons, and consequently under conditions of higher pressure, seems to indicate that the pressure effects have been modified by temperature conditions. It may be emphasized, however, that gypsum will remain as such no matter what the pressure may be as long as the temperature stays below the decomposition point of gypsum at that pressure.

When the pressure forms a non-uniform component the problem resolves itself into a phaseal rule. In applying Riecke's phase rule we find as a general theorem that "the dissociation point at the free surface is depressed in consequence of any stress by an amount dependent on the latent heat and the work done on a unit mass." * The reason that pressure has not the effect of forming anhydrite and water from gypsum is well expressed by Wallace*- "There is an increase of volume in the transformation gypsum to anhydrite and water, and although the liquid phase will at once seek regions of lower pressure, it is the volume relationship at the moment of transformation that regulates transformation conditions."

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*Bowles, O. and Farnsworth, M.: Economic Geology, Vol. 20, 1925, p.743

*Wallace, R. C.: Geol. Mag. 1914, p. 275.

It has been shown by Van't Hoff in his vapor tension experiments that temperature has a very deciding influence on the form in which the calcium sulphate will be deposited. At temperatures above 30° C. anhydrite will be deposited from a solution that is saturated with respect to calcium sulphate and sodium chloride. This primary deposition of the calcium sulphate in the form of anhydrite is of singular importance in the interpretation of gypsum and anhydrite deposits. The presence of relatively high temperatures and strongly saline solutions is to be expected in detached basins of the sea. Such conditions have been advocated by Van't Hoff in his explanation of the Stassfurt beds. Any increase in pressure due to super-deposition of beds would tend to retain the anhydrite in its stable form even though the temperature were to drop.

Gypsum precipitates from a saturated solution of calcium sulphate and sodium chloride when the temperature is below 30° C. This condition according to some writers (Arrhenius and Lachmann)* points with favor to the primary deposition of the sulphate as gypsum and the formation of anhydrite as a secondary product from the gypsum. If calcium sulphate is deposited as gypsum then this gypsum will not change to anhydrite with increasing pressure due to overload even though the temperature might have increased above the critical temperature for gypsum stability. A primary anhydrite deposit at any considerable depth, because of the increase that would take

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*Wallace, R. C.: Geol. Mag., 1914, p. 272.

place on the addition of water and because of the probable absence of waters necessary to bring about the change, will stay as such. To quote from Wallace* - "Geological evidence points unmistakably to a very prolonged lag in the transformation anhydrite to gypsum, and it is not at all likely that at temperatures not much above 30° C. the change goes on more rapidly." In view, then, of these additional factors it seems that gypsum and anhydrite are of primary occurrence. Gypsum deposits of Nova Scotia, Texas, Colorado and Nevada have been assigned definitely to deposits resulting from the hydration of anhydrite deposits. In these cases, however, the anhydrite is considered to have come close to the land surface through denudation. The release of pressure due to a removal of the overburden has also facilitated the hydration processes. In these deposits folded structures would be expected. These secondary gypsum deposits represent the one main exception to the theory of the primary origin of gypsum and anhydrite deposits.

The Zonal Distribution of Gypsum and Anhydrite.

In the previous section of this chapter the writer has presented the fact that gypsum and anhydrite bear a close relationship to one another. The many instances, however, of gypsum occurring comparatively close to the surface and overlying massive anhydrite deposits have led some to the belief that the minerals are distributed in zones. The theory considers that gypsum and

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*Wallace, R. C.: Geol. Mag. 1914, p. 275.

anhydrite occur in depth zones regulated by external physical conditions. If the physical conditions change so as to make one or the other occupy an unstable condition then theoretically the mineral should change to occupy its correct form in the new zone.

Newland* considers that "gypsum is more or less an incidental development, closely restricted in distribution, whereas anhydrite under prevailing geological conditions is the persistent and stable compound." To substantiate this viewpoint, Newland takes as his example the gypsum deposits of New York. By a study of outcrops and drill cores he comes to the general conclusion that the contact between the anhydrite zone and gypsum zone comes between 250 and 300 feet. In Michigan however 500 feet seems to be the maximum depth for gypsum deposits.* One mine in Iowa shows a 13-foot bed at a depth of 533 feet. The deposits at McMurray,* as determined by the Alberta Provincial Government test wells, show massive gypsum occurrences at even greater depths. One of these wells shows the lowest massive gypsum at 760 feet. Newland explains this wide variation in depths on the basis of an equilibrium zone, caused by the slow rate of alteration of one form to the other. From his study of the problem Newland arrives at the conclusion that "From the information in hand it would appear that the stable calcium sulphate mineral under compression represented by a load of more

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*Newland, D. H.: Economic Geology, Vol. 26, 1921, p. 394.

Grimsley: The Gypsum of Michigan: Geol. Survey of Michigan, Lansing 1904, p. 84.

*(Allan, J.A.: Res. Council of Alberta, Rept. No 2, 1920 p 106; Rept. No.10, 1923, p 50)

than a few hundred feet of sediments is anhydrite."

The "gypsum zone" is represented by a comparatively shallow near surface zone. Lying below this zone is the unstable zone followed by the anhydrite zone of indefinite extent. The theory is applied to the change gypsum to anhydrite, as well as to the change anhydrite to gypsum. Deviations in zonal phases are attributed to the influence of ground water or erosion.

The conclusions drawn from this theory do not coincide with the results of the discussion of the genetic relationship of gypsum and anhydrite. Near-surface gypsum deposits were considered to be primary deposits or secondary deposits caused by the action of meteoric waters. The release of pressure merely made it easier for gypsum to form. According to Wallace* it is impossible for anhydrite to form from gypsum due solely to increased pressure.

The major deposition of the $CaSO_4$ as anhydrite, and the subsequent alteration of its upper portion to gypsum is the basis for the theory of zonal distribution. Gypsum beds that have been found lying well below the supposed gypsum zone or below a massive anhydrite bed may be explained in two ways. They may be satisfactorily explained as unaltered primary gypsum deposits. This explanation would be more plausible when the gypsum beds in question show no possibilities of having been hydrated. The deeper the bed, the less would the chances be for hydration. The deposit could justifiably be considered as primary. If the gypsum lay within the unstable

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*Wallace, R. C.: Geol. Mag. 1914, p. 275.

zone and overlain by anhydrite it can be explained as a result of hydration, if the anhydrite band is at some point sufficiently near the surface, or broken, so that meteoric waters could pass below it and hydrate its lower side as well as its upper side. This, in brief, is Brownell's* explanation of the Amaranth deposits of Manitoba.

Brownell, G. M.: Trans. C.I.M.&M., Vol. 34, 1931, p. 292.

Whether or not the "zonal distribution" of gypsum and anhydrite represents an important factor in the determination of the origin of gypsum is hard to say. At the present time the wide variations in zones, and the action of external agencies to disrupt the zones makes it impossible to apply the theory.

Criteria Used in the Determination of Genesis.

Each theory of origin has been advanced and maintained by certain criteria. Since a criterion may be interpreted in different ways a discussion of the separate criteria applicable to different types of deposits will be carried on.

Discussing first the deposits formed by alteration let us consider the criteria of alteration deposits. A summary of the criteria advanced by J. W. Irving in 1911 for replacement ore bodies may be used as a guide in discussing alteration deposits of gypsum. The summary follows:

"1. Form of ore-body, more or less irregular. Gradually fading limits. Not always conclusive.

"2. Presence of unsupported residual rock masses. Some-

times the orientation of bedding may be proved parallel with the surrounding rocks.

"3. Absence of crustification. A banding may be observed in places due to preservation of bedding or shearing planes.

"4. Absence of concave contacts; in limestones, for instance, solution of cavities tends to produce flat concave depressions; a filled cave would show this whereas replacement proceeds with convex outlines toward the unaltered rock.

"5. Preservation of textures and structures of original rock.

"The last-named criterion is the most conclusive."*

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*Lindgren, W.: Mineral Deposits, 4th Edition, 1933, p. 184.

The alteration of anhydrite to gypsum really constitutes an addition reaction in which water is added to the anhydrous calcium sulphate. The comparatively even quality of the altering material, the slow rate at which it alters, and the greater chances for a constant supply of alteration solution; i. e., ground water, all tend towards an even plane of encroachment at which replacement is taking place. Anhydrite exhibits very few, if any, textures that might be retained and recognized in the altered product. Evidence then of alteration must rely on the information obtainable from the transition zone itself. This has been noted by Cole and Rogers*. Small inclusions of anhydrite in gypsum probably represent

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*Cole & Rogers: Mines Br. Rept. No. 732, p. 7.

the remaining criterion to substantiate the theory of the formation of gypsum from anhydrite.

The deposits in which gypsum is considered to have been formed by the action of sulphuric acid on calcium carbonate are much more open to controversy. Discussing this type on the basis of Irving's criteria we find that his first criterion has been extensively applied. The acid solutions have eaten into limestone beds in an uneven manner, producing lenses and irregular blocks of gypsum in the limestone. The size of these blocks and the relative amounts of gypsum would depend on the amount of alteration completed.

Factor number two follows as a direct sequel. Irregular replacement would leave residual masses of limestone or possibly shale included in the limestone. Instances of the bedding plane of the block being parallel with the surrounding rocks have often been cited in support of the alteration theory.

Criterion number three applies more to ore-bodies and has little significance here.

No information sufficient for basing any conclusions has been obtainable with regard to the concavity or convexity of the alteration contacts. Such information might prove to be very useful in application to gypsum deposits.

In the final criterion and the one that Irving considers most conclusive, the theory of alteration by acid solutions breaks down. Gypsum, even when lying in close association with limestone lenses, that by some writers are considered remnants of alteration,

shows a remarkable absence of structures and textures that might indicate alteration.

A study of an enclosed limestone lens can give us a very definite set of criteria which are applicable to this theory. If the limestone block be taken as a remnant of the former limestone bed it would evidence characteristics similar to the limestone bed. Fossils, or at least structures suggestive of fossils, would be expected in the limestone. Jointing and bedding planes, being characteristic of the sedimentary limestone should be evident in the limestone block. The action of acid sulphate solutions on limestone should leave at least two distinguishing features as indications of its presence and action. Segregations of material insoluble to the weak acid solutions would be expected to show an irregular face due to the difference in solubility of the altering limestone. Since the sulphate solutions are considered to have been derived from the oxidation of pyrite then this iron, as well as iron derived from impurities, would deposit as stains in the oxide form.

One other factor, the importance of which seems to have been passed over lightly, is worthy of special note. The formation of gypsum by an alteration process such as we have been discussing involves the presence of non-saline solutions during the formational period. Anhydrite, then, could not be present in a deposit of this type unless the temperature of the solutions were above 66°C.

In the interpretation of a deposit considered to have been formed through alteration by acid solutions all of these

criteria should be applied. For example, Brownell definitely discards the theory of replacement as an explanation of the Amaranth deposits since in no case was he able to apply these criteria.

CHAPTER III

GENERAL GEOLOGY OF GYPSUM DEPOSITS

General Statement.

Until comparatively recent years the data on the geology of gypsum deposits has been available only through the examination of surface outcrops. These outcroppings were few, and in many cases poor because of the softness of the outcropping material. The advent of well-core determinations has opened a new field of investigation and although at first little differentiation was placed between gypsum and anhydrite in the well-cores it has been established that anhydrite predominates over gypsum as the depositional form.

The properties of a gypsum - anhydrite deposit are a result of environmental physical forces such as temperature, pressure and forces of precipitation. At atmospheric pressure and temperatures gypsum is the stable form and it is probably because of this that gypsum is found more frequently in near surface deposits.

The depositional factors of temperature, pressure and salinity which have been dealt with previously explain the relationships of gypsum and anhydrite as geological associates. A rise of temperature above 30°C. in a concentrated saline solution causes a deposition of gypsum to change to a deposition of anhydrite. A temperature of

163°C. or lower will cause gypsum to dehydrate to anhydrite. Pressure effects are chiefly instrumental in the formation of gypsum from anhydrite when such pressure has been decreased sufficiently to allow hydration processes to proceed.

Modes of Occurrence.

The mineral associations of gypsum are of particular importance since it is through these associations that we are able to come to some conclusions as to the manner in which the deposits are formed.

Gypsum itself occurs as rock gypsum, selenite, satin spar, and gypsite. In the study of gypsum it has been found that gypsum shows variations in texture and different modes of occurrence. In some cases the texture of the gypsum is a direct result of the manner of formation of the deposit and as a result may give an indication of the mode of origin.

Rock gypsum is the most common variety and is the type of greatest economic value. It occurs interbedded with sedimentary rocks with colors of white, pink, blue, gray or brown. Banded and mottled structures are common. Alabaster is a particular type of rock gypsum suitable for carving and sculpturing. It is very fine grained, white, and slightly translucent.

An impure form of gypsum thought to be formed by the evaporation of gypsiferous waters is known as gypsite, earthy gypsum or gypsum dirt. The impurities of the deposits are caused by the

simultaneous deposition of clays and sands with gypsum. Although the deposits are usually of small lateral extent and seldom exceed 20 feet in thickness they may be of some economic importance.

Two crystalline varieties of gypsum are known; namely, selenite and satin spar. Selenite occurs in distinct crystals or in broad folia. The pure form is colorless and transparent. Due to these physical properties and its perfect cleavage and flexibility it is sometimes mistaken for mica. It lacks, however, the elasticity of mica. The second crystalline variety, satin spar, occurs as aggregate crystals in needle-like fibres. It has a vein occurrence in or near massive gypsum deposits. Its general association with gypsum deposits is caused by the fact that it is deposited by gypsiferous waters from the gypsum deposits.

Mineral Association.

Gypsum is generally considered to have been derived from the deposition of concentrated saline solutions and as a result salts which are found in sea water would be its natural associates. From an examination of the known deposits it is apparent that anhydrite is the chief associate of gypsum.

In direct agreement with the theory of deposition from saline solutions some gypsum deposits have mineral associations of halite and to a minor degree glauberite. The most complete list of mineral associates so far obtained is that for the Stassfurt deposits of Germany. A list of these minerals as taken from

F. W. Clarke's* work is given below:-

1. Anhydrite ($CaSO_4$)
2. Glauberite ($CaSO_4 . Na_2SO_4$)
3. Polyhalite ($2CaSO_4 . MgSO_4 . K_2SO_4 . 2H_2O$)
4. Krugite ($4CaSO_4 . MgSO_4 . K_2SO_4 . 2H_2O$)
5. Kieserite ($MgSO_4 . H_2O$)
6. Epsomite ($MgSO_4 . 7H_2O$)
7. Vanthoffite ($MgSO_4 . 3Na_2SO_4$)
8. Bloedite ($MgSO_4 . Na_2SO_4 . 4H_2O$)
9. Loernite ($MgSO_4 . Na_2SO_4 . 2\frac{1}{2}H_2O$)
10. Langbeinite ($2MgSO_4 . K_2SO_4$)
11. Leonite ($MgSO_4 . K_2SO_4 . 4H_2O$)
12. Picromerite ($MgSO_4 . K_2SO_4 . 6H_2O$)
13. Aphthitalite ($K_3Na(SO_4)_2$)
14. Kainite ($MgSO_4 . KCI.3H_2O$)

Since gypsum has been taken as a sedimentary deposit it will necessarily be associated with sedimentary deposits such as limestones, dolomites and shales. Although these sedimentary deposits and the gypsum deposits may occur as separate banded layers they may in other instances show a simultaneous deposition with an intermixing of the gypsum and other sedimentary material.

Gypsum of the type gypsite is often associated with and intermixed with loose, unconsolidated, sandy material. Such a

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*Clarke, F. W.: U. S. Geol. Sur. Bull. 700, 1920, p. 224.

deposit is likely to have been derived from arid conditions and represents the more probable source of aeolian gypsum deposits.

Classification of Gypsum Deposits.

Gypsum has been classified according to the theories advanced for origin and according to its modes of occurrences. Bell's* classification follows the modes of occurrence whereas Wilder's* is based on origin. These classifications are given below:

Classification by W. A. Bell

Class A - Due to the evaporation of sea water.

Subclass (a) - In marginal salt pans - shallow depressions along a sea margin into which the sea water finds intermittent entry by overwash at high tide, during storms, or during seasonal inshore winds.

Subclass (b) - In marginal salinas. A salina is a marginal depression at or near a seashore, superficially cut off from the sea by a bar or other barrier that is nevertheless pervious in whole or in part to the sea water.

Subclass (c) - In sea lagoons. Lagoons differ from salt pans in greater depth, and connection with the open sea is not rapidly intermittent but is continuous over or through a bar or barrier for long intervals of time.

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*Bell, W. A.: Geol. Sur. Can., Mem. 155, 1929, pp. 81-88.

*Wilder, F. A.: Bull. Geol. Soc. Am., Vol. 32, p. 394.

Subclass (d) - In relict seas - inland depression with sea water completely severed from the body. (Partake of qualities of both (a) and (b)).

Subclass (e) - Accumulation of cyclic salts; i. e., of salts carried inland from the sea by winds. (Partake of qualities of both (a) and (b)).

Class B - Continental concentrations of disseminated gypsum.

Subclass (a) - In inland lakes.

Subclass (b) - In river valleys.

Subclass (c) - As surface efflorescences.

Subclass (d) - In spring deposits.

Subclass (e) - As dunes or wind-blown deposits.

Class C. - Vein deposits.

Class D. - Products of alteration or replacement.

Classification by F. A. Wilder.

A. - Deposits formed by concentration of material disseminated through sediments.

(1) In inland basins.

(2) On the surface.
  (a) by springs
  (b) As efflorescence

    a' further concentrated by wind.
    b' further concentrated on slight depressions by surface waters.

(3) In fissures, cavities and as replacements.

B. - By alteration.

(1) of carbonates

(2) of anhydrite.

C. - Deposits formed directly by evaporation of sea water.

CHAPTER IV

GYPSUM OCCURRENCES.

Geographical Occurrence in Canada.

Gypsum is known to occur in nearly every province in the Dominion as shown on the index map in the folder. Some of these deposits in the various provinces have not been exploited due to the difficulties presented in transportation, mining, or the quality of the deposits. Such deposits, however, because of their economic possibilities are worthy of some note. Deposits occur in Nova Scotia, New Brunswick, Quebec, Ontario, Manitoba, Alberta, British Columbia and the North West Territories. The only occurrences of gypsum in Saskatchewan consist of surface deposits of selenite crystals.

The gypsum deposits of Nova Scotia are widely distributed throughout the province and represent the largest known deposits in Canada.** They can be separated into the Cape Breton Island group (Fig. 1) and the Mainland group. (Fig. 2) Cape Breton Island has occurrences in Victoria, Richmond and Inverness counties. The Mainland has occurrences in Antigonish, Cumberland and Hants counties.

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*Jennison, W. F.: Mines Branch Rept. No. 84, 1911.

*Cole, L. H.: Mines Branch Rept. No. 714, 1930.

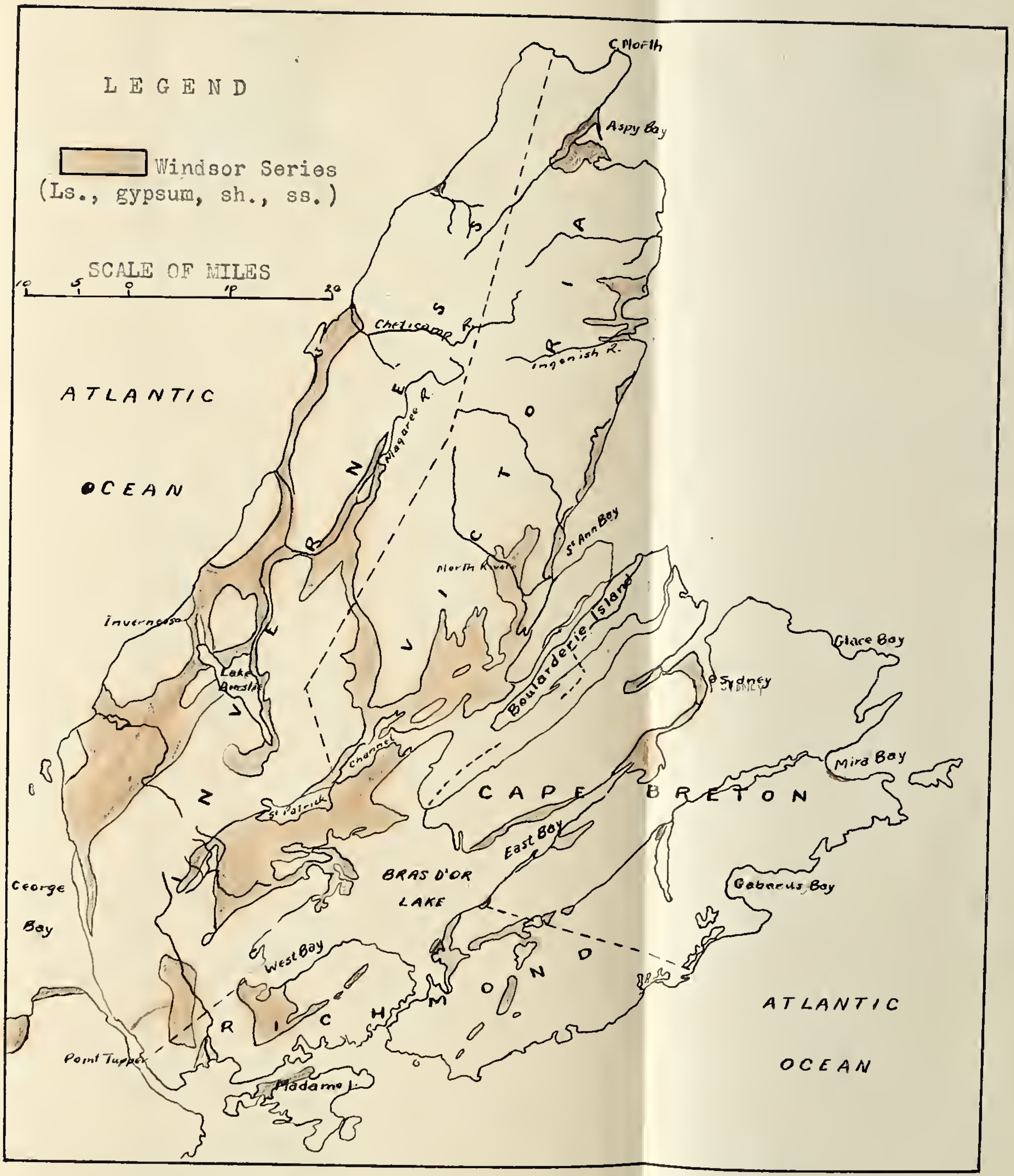

Figure 1. Sketch map showing gypsum occurrences in Cape Breton Is., N. S.

(Copied from L. H. Cole.)

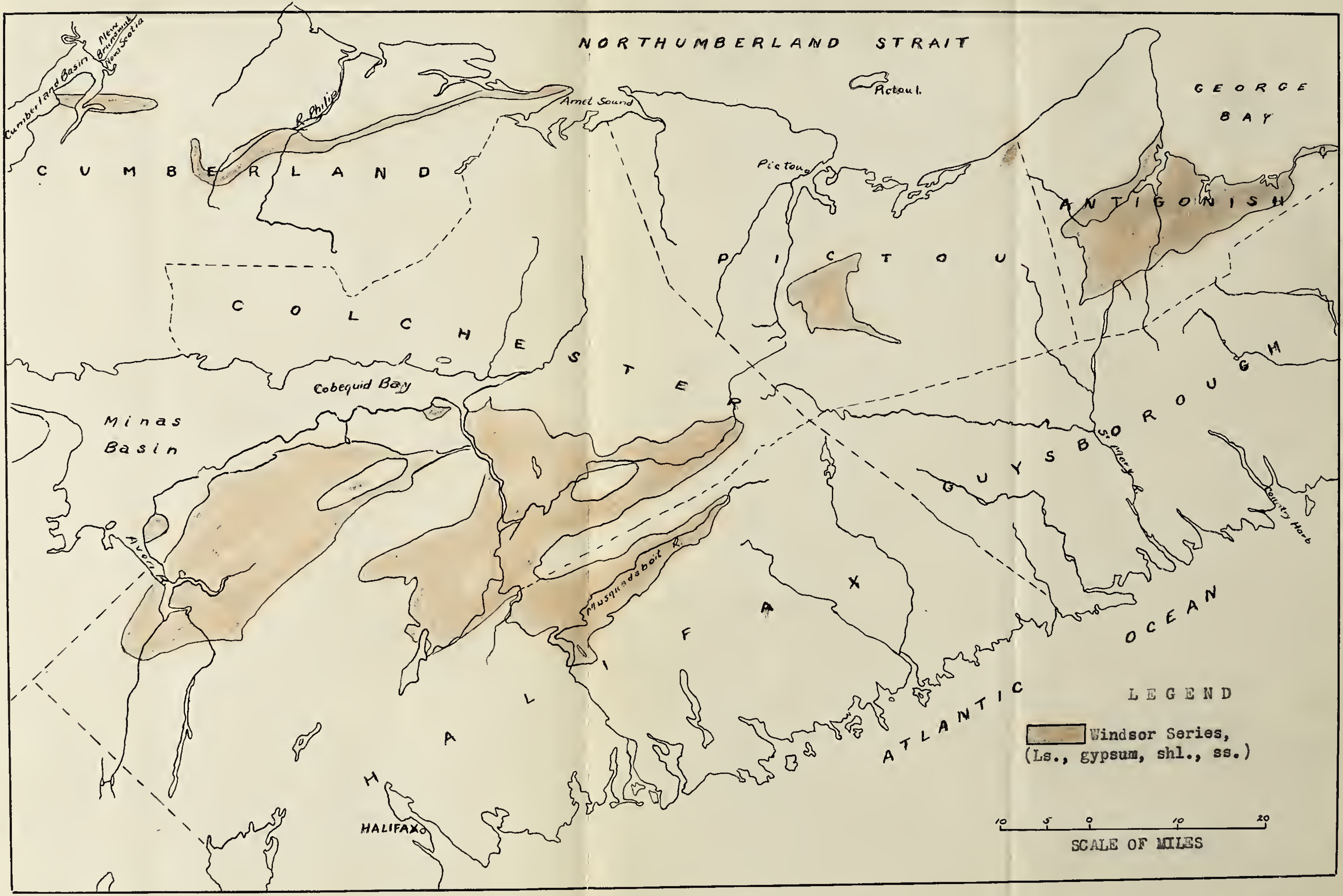

Figure 2. Gypsum occurrences on Nova Scotia mainland.

(Copied from L. H. Cole.)

The gypsum occurrences of New Brunswick are located as shown in the accompanying sketch map. (Fig. 3). Although the Hillsborough deposits are the only ones that have been extensively developed the deposits are of great economic importance to New Brunswick. The white translucent variety known as alabaster is of importance in these deposits. The more important deposits are in St. John, Kings, Westmorland and Albert counties in the south, and Victoria county in the north.

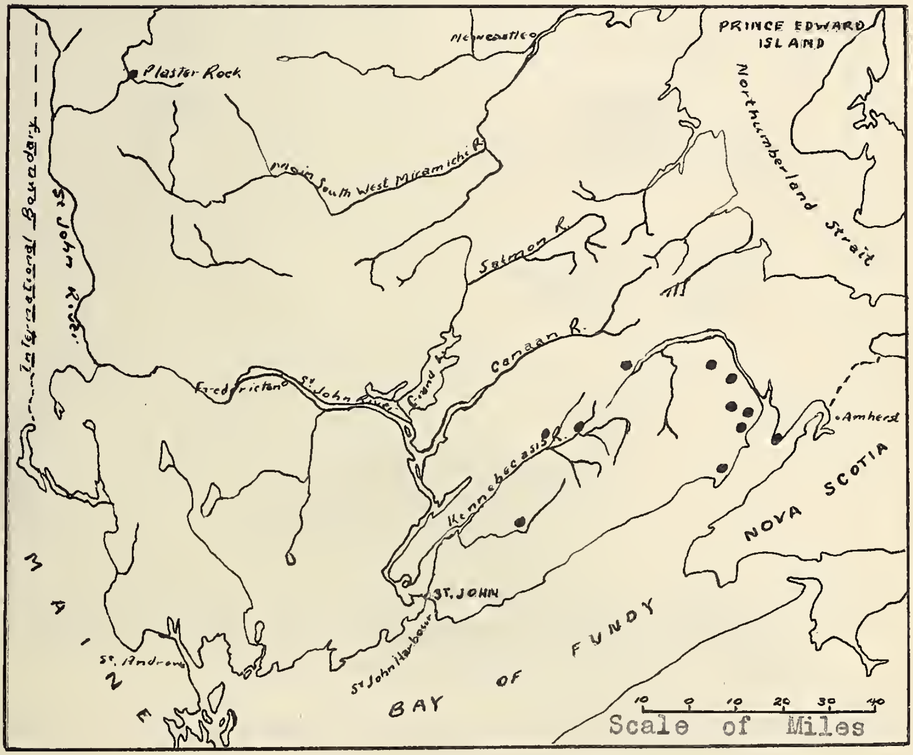

Figure 3. Sketch map of part of New Brunswick showing distribution of occurrences of gypsum.

(Copied from L. H. Cole.)

As far as is known the only deposits of gypsum in Quebec occur in the Magdalen Islands in the Gulf of St. Lawrence. Gypsum deposits occur on four of the ten islands. These are Grindstone, Alright, Amherst and Entry islands. (Fig. 4).

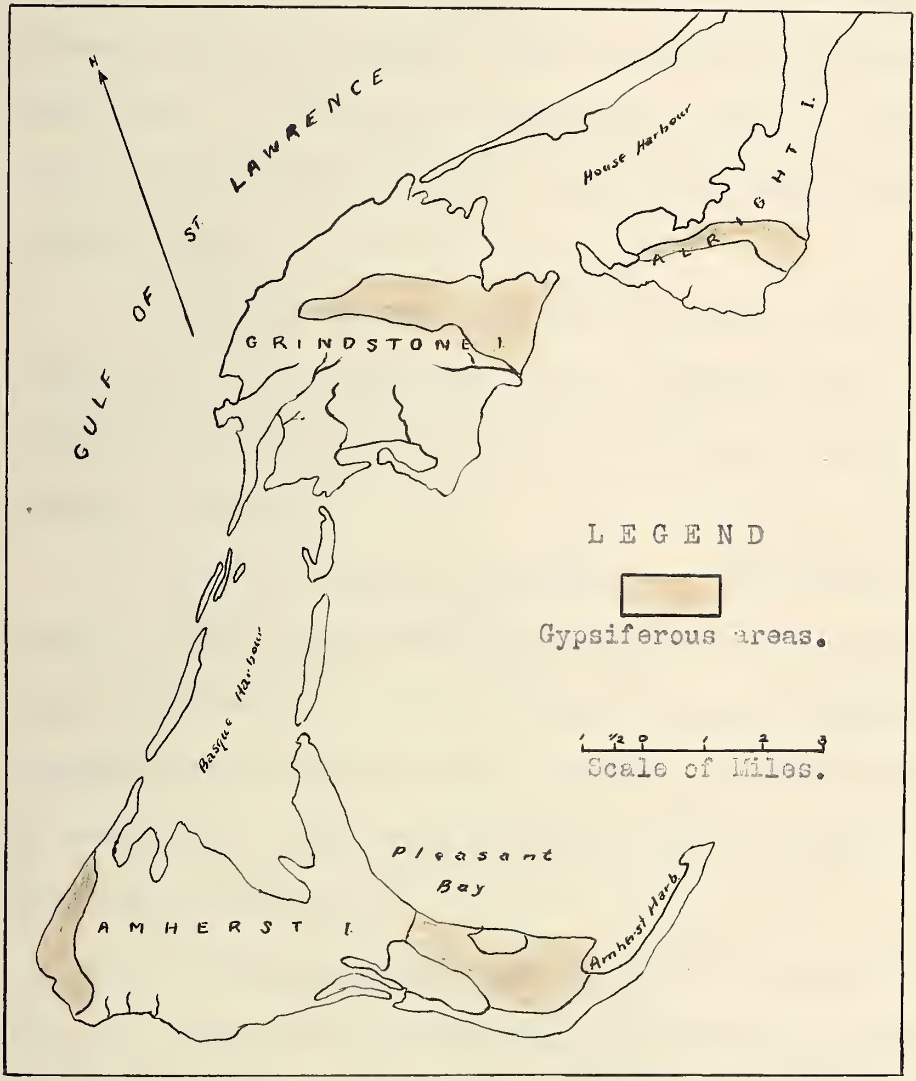

Figure 4. Map of the Magdalen islands showing gypsum areas. (Copied from L. H. Cole.)

Although gypsum deposits have been found in several localities in Ontario only two of these localities contain deposits of any considerable extent. These two districts are Moose River basin (Fig. 5), and the Grand River area. (Fig. 6). Due to transportation difficulties the Moose River deposits have not been developed.

Although numerous deposits are known to occur in Manitoba only two of these deposits have produced gypsum. These are the Gypsumville deposits, and the recently opened Armaranth deposits. (Fig. 7).

Since the deposits of Alberta are to be dealt with in detail it will be sufficient at this point to merely enumerate the gypsum occurrences. Gypsum has been found at McMurray, on the Athabaska river 28 miles north of McMurray, on the Peace river, in Jasper Park, and in many well-cores in the southern part of the province. (Fig. 9).

In British Columbia gypsum is known to occur at the following places: the Falkland deposits in the Kamloops Mining Division; the Spatsum deposits in the Ashcroft Mining Division; the Mayook, Wardner and Bull River deposits in the Fort Steele Mining Division; and the Britannia Mine deposits at Howe Sound. Gypsite is known to occur in the Nicola, Ashcroft, Clinton and Similkameen Mining Divisions. (Fig. 8).

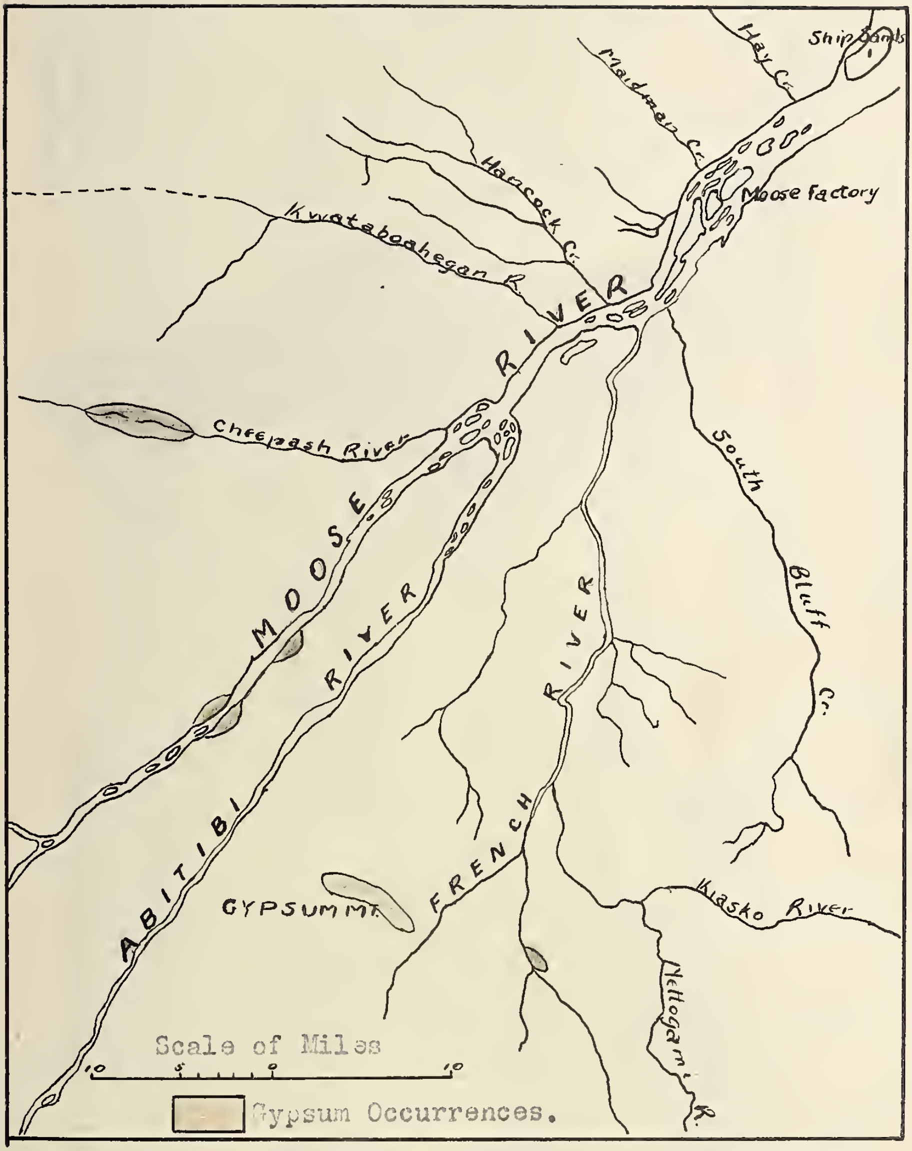

Figure 5. Sketch map showing gypsum occurrences in northern Ontario.

(Copied from L. H. Cole - after Dyer.)

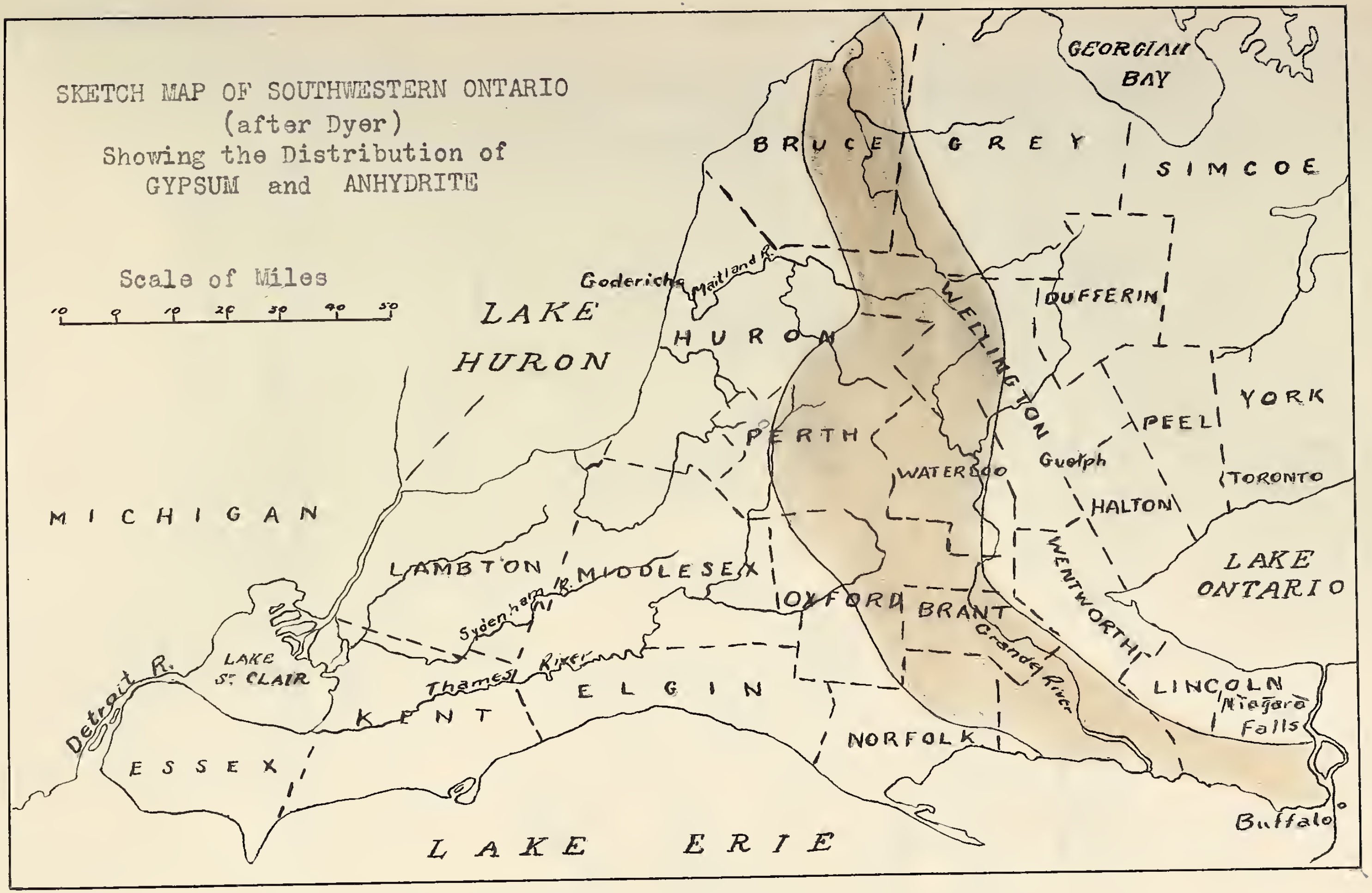

Figure 6. (Copied from L. H. Cole.)

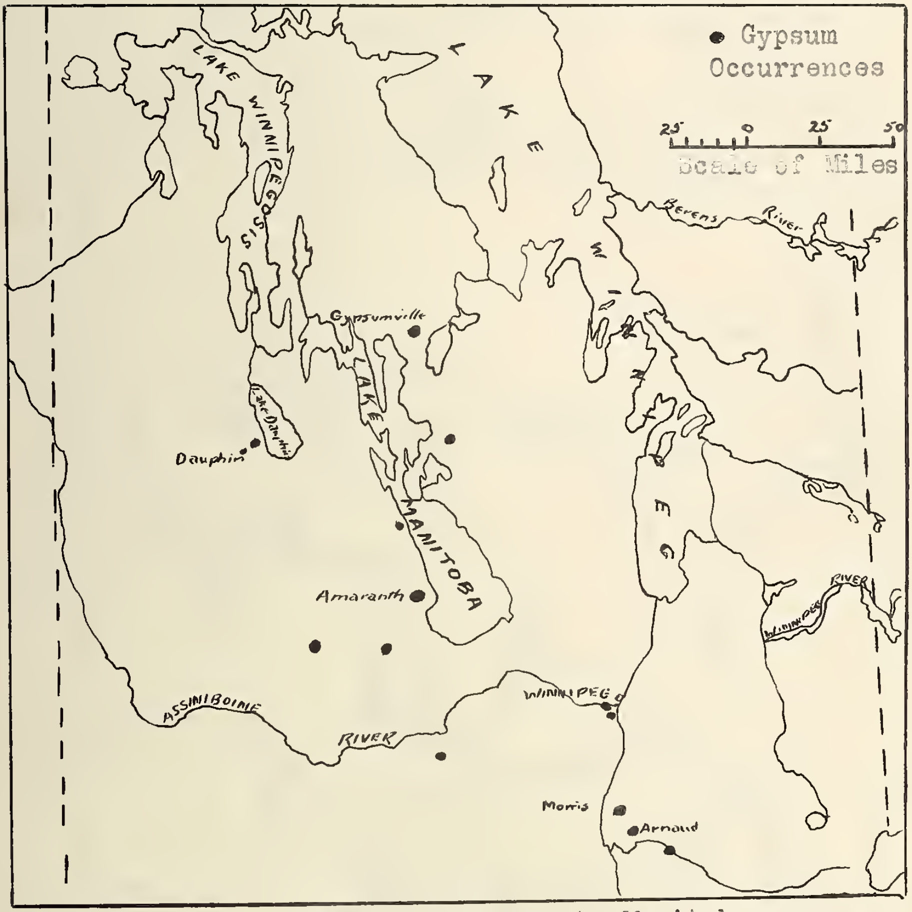

Figure 7. Gypsum occurrences in Manitoba.

(Copied from L. H. Cole.)

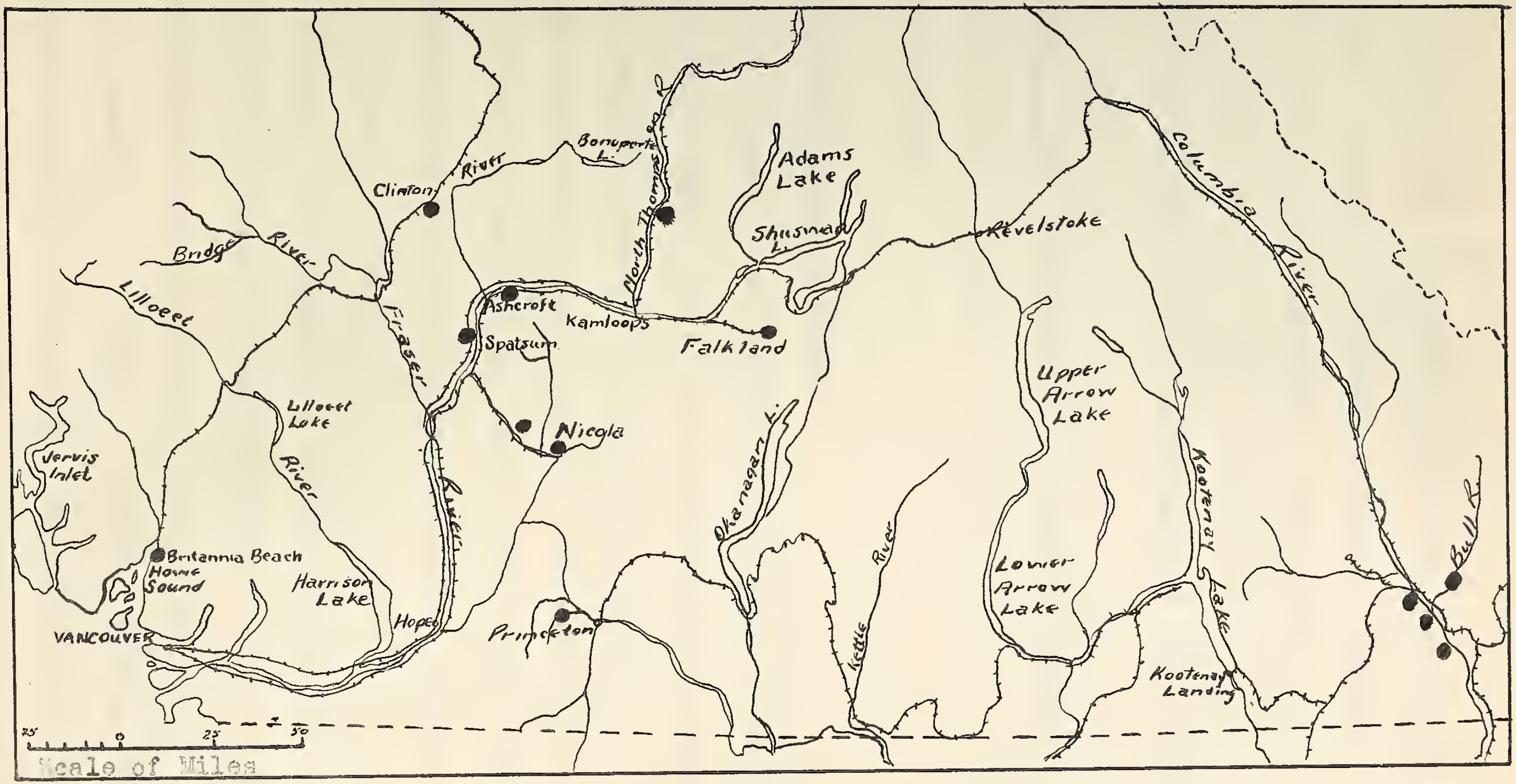

Figure 8. Gypsum occurrences in British Columbia.

(Copied from L. H. Cole.)

Gypsum occurrences have been noted in the North West Territories by Camsell, McConnell, Dawson and Cameron. A small deposit occurs on the north shore of Great Slave Lake at Gypsum Point.* Another deposit occurs about two miles west of Fort Norman at Bear Rock*. Deposits are also known to occur on Great Bear river and on the Mackenzie between the mouths of the Liard and Bear Lake rivers.

Age of Canadian Gypsum Deposits.

The summation and tabulation of the ages of Canadian gypsum deposits should, if all data were clear and undisputed, give the reader an idea of the correlative deposits in Canada. It is the hope of the writer, however, that such will not be the meaning taken from the included table since in many cases the ages of Canadian deposits are not definitely known. Such ages are to be taken as tentative until definite proof as to their correct age is obtained. The inability to obtain information is due primarily to the absence of fossils within a gypsum deposit. This necessitates the investigation of fossiliferous beds above and below the deposit itself. When such information is lacking lithological correlations have been relied upon. The Amaranth gypsum deposits of Manitoba, the McMurray deposits of Alberta, and the Ontario deposits at Moose River and Grande River are examples of deposits

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*Cameron, A. E.: Geol. Surv. Can. Summ. Rept. 1921, p. 33.

*McConnell, R. G.: Geol. Surv. Can. Ann. Rept., Vol IV, Pt. D, p.101.

which have exhibited this difficulty of age determination.

Nova Scotia

Nova Scotia Mainland - Lower Carboniferous. (L. H. Cole.)
Cape Breton Island - Lower Carboniferous. (L. H. Cole.)

New Brunswick - Lower Carboniferous. (L. H. Cole.)

Quebec

Magdalen Islands - Lower Carboniferous. (W.F.Jennison.)

Ontario

Moose River - Upper Silurian. (M. Y. Williams.)

Grand River - Upper Silurian. (G. E. Cole.)

Manitoba

Gypsumville - Silurian. (A. MacLean and R. C. Wallace.)

Amaranth - Devonian. (S. R. Kirk.)

Saskatchewan - Surface deposits. Recent. (L. H. Cole.)

Alberta

McMurray - Upper Silurian or Devonian. (J. A. Allan.)

Jasper Park - Lower Triassic. (J. A. Allan.)

(Refer also to data supplied by Wm. Calder, Director of the Petroleum and Natural Gas Division, Department of Land and Mines, Government of the Province of Alberta, page 49 .)

British Columbia. No brief classification possible.

North West Territories. Middle Devonian. (Chas. Camsell.)

CHAPTER V.

ALBERTA GYPSUM DEPOSITS.

Introduction.

The greater portion of the available written material on the gypsum deposits of Alberta has been presented by Dr. J. A. Allan of the University of Alberta. Occurrences in the region between Peace and Slave rivers have been described by Dr. Charles Camsell.* Dr. A. E. Cameron* of the Mining Department of the University of Alberta has examined and written on the deposits of Peace River.

The list of Dr. Allan's reports has been included in the bibliography accompanying this report but for the convenience of the readers this list has been consolidated and placed with this section: Research Council of Alberta Reports, No. 1, 1920, p. 87; No. 2, 1921, p. 102; No. 10, 1924, p. 48; No. 27, 1932, p. 27. Trans. C. I. M. M., 1929, pp. 232-254; 1933, pp. 1-17.

Some of the Alberta deposits such as those at Jasper Park andPeace Point were observed in surface outcroppings. Knowledge of the McMurray deposits and several deposits in the southern part of the province has been obtained by means of drill-core

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*Camsell, Chas.: G. S. C. Summ. Rept. 1916, p. 134.

*Cameron, A. E.: Research Council of Alberta, Rept. No. 25, 1929, p. 39.

data. In these cases no beds are showing. In other cases certain phenomena have led to the belief of the occurrence of gypsum. The mineral association of salt and gypsum points towards the possibility of a gypsum occurrence 27 miles north of McMurray at La Saline where strong saline springs are found.

General Location of Alberta Deposits.

The accompanying sketch map of Alberta (Fig. 9) has been included to show the locations of Alberta gypsum occurrences. The northern part of the province contains the greater portion of the workable gypsum deposits. The deposits of the south have been encountered in well drilling and present no economic value.

The information as obtained from Mr. William Calder, Director of the Petroleum and Natural Gas Division of the Alberta Department of Lands and Mines is here transcribed. The information has been used directly in the location of gypsum occurrences on the outline map.

The following table gives the name and location of each well with the interval over which bands of gypsum or anhydrite occur. It is necessary to point out that in most cases the actual thickness of gypsum or anhydrite constitutes but a small portion of this interval.

Well	Location	Interval of Occurrence	Age
1. Prov. Govt. Salt Well #1	21-89-9 W.4	500-685	Pre-Upper Devonian.
2. " " " " #2	32-88-4 W4	(415-587 (766-782	" " "
3. Athabasca Oils Ltd. #1	36-95-11 W4	590-720	" " "
4. Von Weymarn Clearwater #1	35 mi. East of McMurray.	350-390	" " "
5. Ribstone #2	5-25-46-1 W4	2900-3080	? Devonian
6. Eyremore #1	1-26-17-18 W4	4830-5120	"
7. Roth #1	4-6-13-5 W4	3870-3920	"
8. Burdette #1	-8-11-11 W4	3780-3810	"
9. Comm. Milk River #1	8-9-3-15 W4	3880-4230	
		5154-5196	Ordovician or Silurian
10. Erickson Coulee #1	13-8-1-12 W4	3590-3650	Devonian
11. Wabash #1	Morley Indian Reserve.	1795-2020	Carboniferous
12. Herron #1	5-24-22-6 W5	2890-3095	"
13. Model #2	16-22-20-3 W5	6080-6240	"
14. C. D. & P.	10-21-19-3 W5	4290-4490	"
15. H. B. Highwood #1	8-1-18-3 W5	2505-2705	"
16. Pekisko Hills #1	6-6-17-2 W5	1510-1790	"

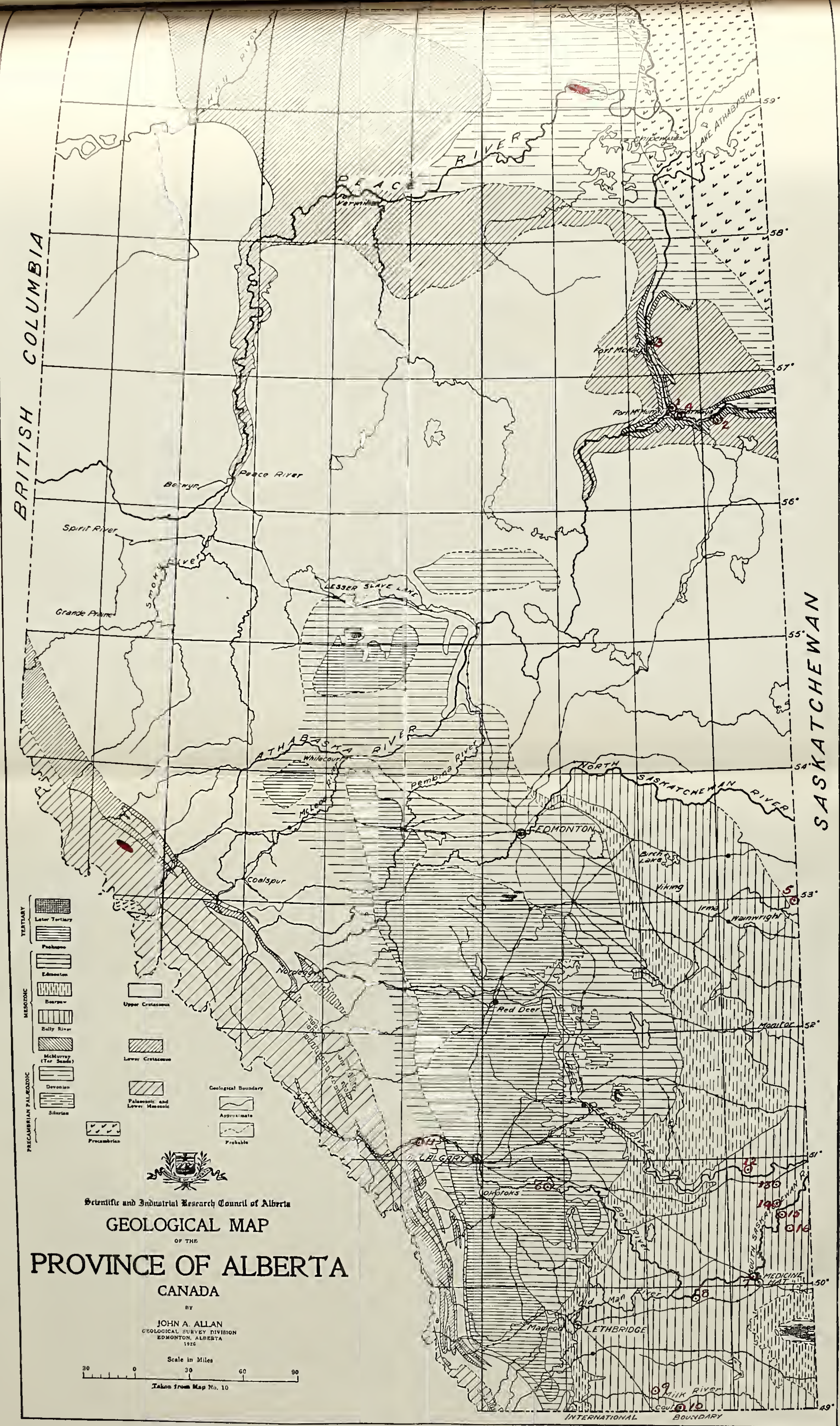

Figure 9. Gypsum occurrences in Alberta.

JASPER PARK GYPSUM DEPOSITS.

Location of the Deposit.

According to Allan* this deposit "is situated near the eastern edge of the Rocky mountains in Alberta, towards the north end of township 51, and the south part of township 52, in range 5, west of the 6th meridian. This location is approximately forty miles north and twenty-four miles west of Jasper." The exact location of the deposits was at one time in some doubt. Although the north boundary of Jasper Park has been defined (Statutes of Canada, 1930, Chapter 33, p. 10) the lack of a survey in the area made definite location difficult. Added to this the general geography had, previous to Allan's work, been incorrectly shown. Allan has come to the conclusion that the deposits lie entirely within the park boundaries. (See Fig. 10).

General Character of the District.

The area containing the gypsum deposits is situated in eastern belt of the Rocky mountains. The main gypsum series is situated in a ridge between Rock Creek and a branch of Mowitch Creek. Observations so far have not included the strata to the northwest and southeast past the Athabasca Valley and it is not known positively whether or not these beds contain gypsum.

The gypsum-bearing rocks of this ridge are all situated

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*Allan, J. A.: Trans. C.I.M.M.,1933, p. 2.

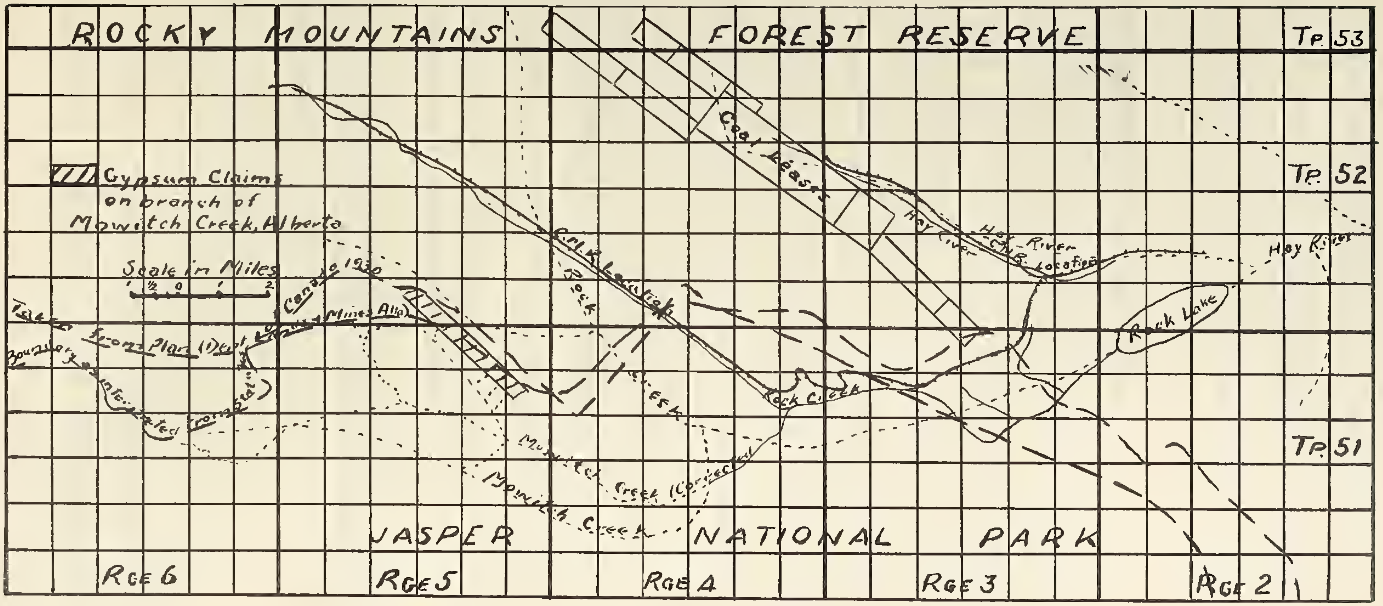

Figure 10. Outline map of Jasper Park deposits. (Copied from J. A. Allan)

above timber-line giving well exposed outcrops of the section. Weathering of the soft gypsiferous rocks has produced talus slopes. Because of this, outcroppings of the strata below the gypsum horizons have often been covered.

Geology of the Jasper Park Deposits.

The strata containing the gypsum deposits have an average strike of N. 35° to 45° W., with a dip ranging from 35°W. to 78°W. Round and gradual slopes as caused by weathering are characteristic. The geological section was studied and measured by means of gulches which cut into the main gypsum ridge. This section, from youngest to oldest, of approximately 700 feet thickness, is composed of four series.*

(1)	Grey hard limestone and sandstone series.	250 feet.
(2)	Yellow to buff weathering series consisting of shale and gypsum-bearing rock.	67 feet.
(3)	Red-bed series of interbedded red, buff, and yellow shales, gypsum beds, and dolomitic limestone.	165 feet.
(4)	Main gypsum series.	220 feet.

A columnar section of the gypsum deposits on Mowitch creek as compiled by Allan has been transcribed and is presented on the following page. The fourth series is presented in a more detailed form as a diagrammatic columnar section.*

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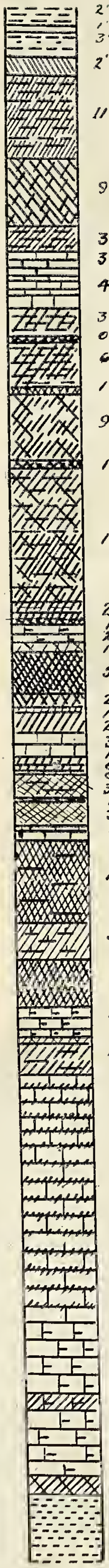
*Allan, J. A.: Trans. C.I.M.M., 1933, p. 7.

*Allan, J. A.: Trans. C. I. M. M., 1933, p. 10.

	Feet
Sandstone, massive, hard, crossbedded	20
Shale	85
Limestone, massive with chert nodules	18
Limestone, massive shaly with quartzite beds	13
Limestone, shaly	25
Limestone, hard (2 ft. grey and 6 ft. blue)	8
Limestone, hard, blue	16
Limestone, shaly	14
Limestone, massive blue	9
Series No. 1 Total	208
Shale, creamy-yellowish to pink	40
Limestone, pink to red	10
Limestone, red to pink, with gypsum bands and stringers	8
Limestone, fine-grained, pinkish	9
Series No. 2 Total	67
Red-beds	3
Limestone, reddish to yellowish, shaly, with gypsum stringers	25
Limestone, black hard cherty band	4
Gypsum bed, yellowsh to cream colored (impure).......	13
Covered	50
Red-beds	20
Limestone, yellow, cavernous, cliff-forming, arenaceous	25
Covered	25
Series No. 3 Total	165

COLUMNAR SECTION
GYPSUM DEPOSITS
in
Tps. 51 & 52, Rge. 5, W. 6 M.
Alberta.

(Compiled by J. A. Allan)



2'0" Yellow beds.
1' 0" Gypsum, white
3' 5" Red beds to yellowish
2' 7" Gypsum, white
11'8" Gypsum rock with angular cherty fragments
9'5" Gypsum rock, white
3'7" Gypsum rock, and hard cherty rock
3'2" Ls. with porous yellowish lenses.
4'9" Ls., hard cherty with 1 foot gypsum rock in centre
3'8" Gypsum, white, banded with cherty layers
0'10" Gypsum, pure white lenses, (10 ft. long)
6'6" Gypsum rock, broken
1'0" Limestone, hard, cherty
9'0" Gypsum rock, dark grey
1'0" Gypsum, very white pure
18'7" Gypsum, grey with hard cherty fragments Upper 4' mottled gypsum.
2'4" Gypsum, mottled white, (broken)
1'0" Gypsum rock, grey
2'5" Limestone, hard cherty
1'6" Gypsum rock, hard grey
5'6" Gypsum, mottled
2'0" Gypsum rock, massive dark grey
1'0" Gypsum rock, dark grey
2'8" Gypsum, white to grey
3'5" Limestone, Thin bedded hard blue
1'3" Gypsum, irregular lensy bed
0'11" Gypsum, banded with hard limestone
0'5" Limestone, hard blue
3'0" Gypsum, white ~~[illegible]~~ with 1 inch shale parting
1'0" Shale, thin bedded
3'0" Gypsum, white dense banded
2'0" Limestone, yellow cavernous
12'0" Gypsum, white with shale lenses.
5'0" Gypsum rock with cherty limestone
7'0" Gypsum, white (lense to 3 ft)
4'0" Limestone, thin bedded cherty with stringers of gypsum
1'0" Gypsum rock, dark grey
4'5" Gypsum bed interbedded with shale
15'0" Limestone, thin bedded with buff to yellow porous gypsum.
23'0" Limestone, black massive cherty with gypsum in rocks.
22'0" Limestone, cherty, interbedded with a 2 foot gypsum bed 5 feet from base
2'5" Gypsum rock, hard dark massive
10'0" Sandstone, massive, buff, cross bedded

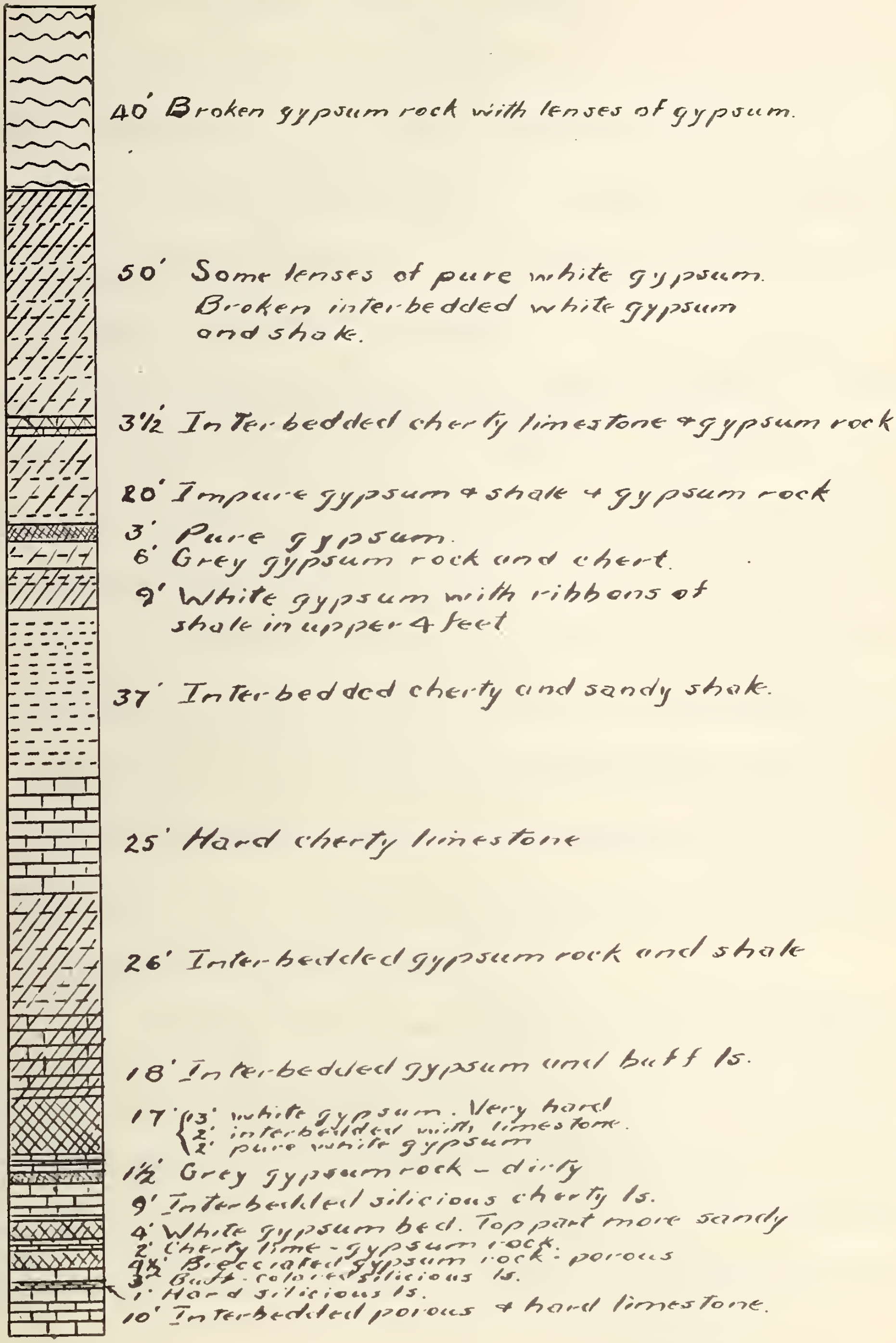

40' Broken gypsum rock with lenses of gypsum.
50' Some lenses of pure white gypsum. Broken inter-bedded white gypsum and shale.
3½' Inter-bedded cherty limestone + gypsum rock
20' Impure gypsum + shale + gypsum rock
3' Pure gypsum.
6' Grey gypsum rock and chert.
9' White gypsum with ribbons of shale in upper 4 feet
37' Inter-bedded cherty and sandy shale.
25' Hard cherty limestone
26' Inter-bedded gypsum rock and shale
18' Inter-bedded gypsum and buff ls.
17' {13' white gypsum. Very hard
2' interbedded with limestone.
2' pure white gypsum
1½' Grey gypsum rock - dirty
9' Interbedded silicious cherty ls.
4' White gypsum bed. Top part more sandy
2' Cherty lime-gypsum rock.
4½' Brecciated gypsum rock - porous
3' Buff-colored silicious ls.
1' Hard silicious ls.
10' Interbedded porous + hard limestone.

Figure 12. Columnar Section Gypsum Series, Corser Gulch, tp. 51, range 5, W. 6th M. (Compiled by J. A. Allan.)

The gypsum included in the buff series of buff, yellow and pink shales and shaly limestones is granular in character. None of the gypsum in the third or Red-bed series is of a pure character. A notable feature of the Red-beds is the presence in them of a cavernous limestone. If gypsum once filled these cavities leaching has removed the gypsum.

The fourth or main gypsum series* consists of numerous bands of gypsum interbedded with limestone, sandstone and shale. Much of the gypsum is of an impure nature. The thickest beds of pure gypsum encountered was twelve feet thick. A dominant feature of the pure deposits is its lensy character and it is because of this tendency to lens that the quantity of pure gypsum is cut down considerably, and with this feature the economic possibilities of the deposits diminish. Since the main gypsum series contains only a small part of its thickness as pure gypsum the valuable part of the deposit is relatively small.

*(Allan, J.A.: Trans. C.I.M.M., 1933, p. 7)

The gypsum shows two common characteristics(1)Pure white gypsum with saccharoidal texture indicates erosive action.(2)The irregular patching of gypsum with numerous fragments of dolomitic limestone in many of the beds to produce a mottled appearance gives an indication of the original impurity of the sediments making up the deposit.*

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*Allan, J. A.: Trans. C. I. M. M., 1933, p. 11.

No anhydrite has, as yet, been detected in the deposit. The absence of anhydrite may be due to a non-deposition of anhydrite or a subsequent alteration of

the anhydrite to gypsum.

Economic Considerations of the Deposits.

Several factors must be considered in the economics of the Jasper Park deposits. From the foregoing discussion it would seem that the amount of pure, workable gypsum is not very great. Further investigation might, however, uncover more and sufficient amounts of gypsum to warrant its exploitation. Transportation of the gypsum represents a difficult problem. The character of the deposit might in some portions necessitate expensive underground mining methods to clear the gypsum. Since the deposits are within the Jasper Park boundaries they cannot, at least for the present, be worked because government regulations prohibit the development of mineral deposits within the park boundaries. Under such conditions, then, it hardly seems probable that the deposits will be of economic value.

Age of the Deposits.

According to Allan, "this gypsum deposit occurs in strata of Triassic age and near the top of the formation because these beds are overlain by marine shale belonging to the Fernie formation which is Jurassic in age." This series is thought to correspond to the Spray River formation. Allan considers that the gypsum series is lower than McLearn's Schooler Creek formation.* A correlation has been advanced between the limestone beds above the

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*McLearn, F. H.: Geol. Surv. Can. Summ. Rept. 1920, Pt. B.

Red-beds and buff series and the beds immediately below the Fernie and the Schooler Creek formations.

Origin of the Jasper Park Gypsum Deposits.

A study of the conditions in the Jasper Park deposits show that the deposit lends itself to certain main criteria of one theory of origin and yet breaks away from such a theory because of the presence of certain other important features. An example of this is seen in the fact that although the deposit is associated with marine deposits (an indication of deposition from sea waters) it is at the same time devoid of all life that would be thought of as being associated with marine conditions.

In order, then, to arrive at a correct or even plausible explanation for the origin of the deposits it is necessary to present all the material as obtained from scientific research that would be of value in the determination. Anhydrite has not as yet been detected in surface outcroppings of the deposit. Whether or not anhydrite is present at depth is unknown. The absence of salt is a second feature of the deposit. Other factors which form important criteria for the determination of origin are the marine associations, conditions which indicate aridity, the lensy character of the deposit, contortion of some of the smaller beds of gypsum and the mottled character of the gypsum. Among the specific reasons in support of this theory that the deposit has been formed by the direct evaporation of sea waters are the following:-

(1) The deposits are associated with marine sedimentary deposits such as shale, limestone and dolomite. Overlying the deposits are marine sediments of Jurassic age.

(2) Indication of aridity during depositional times by the presence of the red, yellow and buff-colored beds.

(3) The presence of mottled gypsum and dolomitic limestone indicates a contiguous association of marine deposits and gypsum deposits.

(4) Conformity of the gypsum bands with the interstratified sedimentary deposits.

Other factors pertaining to the deposit, however, will not lend themselves directly to such a theory and if the theory is to be retained they must be explaind. Most important of these are:-

(1) Entire absence of fossils in the gypsum deposit or directly associated sedimentary bands.

(2) Entire absence of salt or any indications of former presence of salt.

(3) Absence of anhydrite.

The absence of fossils has long been an obstacle to the protagonists of the Oschenius bar theory. One explanation has been advanced by Branson in his modified bar hypothesis. This theory satisfactorily explains the problem, but cannot

be verified by field determinations. The problem is not peculiar to the Jasper Park deposits and since the theory has been applied to other deposits of a similar type it is acceptable in this case.

The next two problems, when looked at separately, represent serious hindrances for the theory of sedimentary deposition, but, when studied in relation to one another, an explanation seems plausible. These conditions become involved with the findings of Van't Hoff; namely, that upon the evaporation of sea water calcium sulphate will precipitate first in the form of gypsum, but as concentration proceeds to the point of saturation for sodium chloride, the gypsum changes to anhydrite when the temperature reaches 30°C. The field observations then indicate, since neither anhydrite nor salt were found, that external agencies kept the concentration of the salines below the concentration necessary for the deposition of salt and also kept the temperature of the salines below 30°C. There are two general factors which might have been instrumental in keeping the concentration of salt down and still retain a concentration sufficient for gypsum deposition. The first of these could be described as a local condition wherein water was being added to the basin by means of rivers. This might also be an adequate explanation of the finely interbedded character of the gypsum and sedimentary shale beds as the shale could be thought of as being derived from the material transported by the rivers. The second possible explanation of the problem would depend upon the presence of an undulating

coast-line at the time of deposition. Advances of the sea would serve to flush the marginal basins of its concentrated salt waters and still leave previously deposited gypsum as such. Periods of recession would serve as periods of concentration for the sea-water trapped in the basins. This theory seems well in line with Branson's modified bar theory and at the same time gives an explanation for the interstratified sedimentary beds. The presence of such a sea has been suggested by Allan as extending in a narrow strip from the International boundary line northwards to the Athabaska valley.*

One other distinctive feature of the deposits is the fact that arid conditions prevailed in inter-depositional periods. Evidence of this is seen in the presence of the red-beds overlying the deposits, the saccharoidal texture of some of the gypsum and the presence of gypsum lenses formed by wind action. The bearing of this condition of aridity seems in the main to be incidental to the depositional theory. It would more than anything be a modifier of the previously deposited gypsum and should in no way form obstacles to the depositional theory.

The presence of pyrite nodules near the base of the deposit gives at least a suggestion of origin by alteration processes. The position and small amounts of such pyrite, however, seem to minimize such a possibility. No other factors such as included limestone blocks, irregular gypsum masses or subsurface oxidation

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*Allan, J. A.: Trans. C.I.M.M., 1933, p. 16.

stains, which would be suggestive of alteration have been noted.

It seems then that the alteration theory cannot be applied to the deposit.

Two possible methods of formation remain. The deposit might have been formed by the concentration of disseminated salts in a desert basin. Such a theory proves much too inadequate as a means of origin as was explained by Dyer.*

The remaining theory that would place the gypsum as a result alteration from anhydrite receives little evidence for its support. If the deposit was originally formed of anhydrite it has subsequently been altered entirely to gypsum since no anhydrite has been found. Total alteration with no evidence of remnants from alteration seems improbable. Some highly contorted gypsum beds a few inches thick do occur and suggest the possibility of anhydrite alteration to give the folded structure. This is disputed again by the fact that the associated beds also show contortions. The contortions in this case have been formed by orogenic movements. Wind action has had an important effect in the formation of gypsum lenses in the deposit. Such dunal lenses have been formed by the concentrating action of winds on disseminated deposits that were exposed during a stage in the formation of the deposit.

As a conclusion to our discussion on the origin of the Jasper Park deposits at Mowitch creek, it seems reasonable to say

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*Dyer, W. S.: Ont.Dept. Mines, Ann. Rept., Vol. 34, Pt. II, 1925, p. 39.

that the deposits cannot be considered as having been derived from the alteration of anhydrite by hydration or from the alteration of limestone by acid sulphate solutions. The concentration of disseminated salts in a desert basin proves too inadequate a theory to account for the size of the deposit. The deposit, then, can best be designated as a primary deposit formed by deposition from concentrated saline solutions.

THE GYPSUM DEPOSITS OF PEACE RIVER

Introduction.

The gypsum deposits on the lower Peace river near Little Rapids were first studied by Camsell in 1916.* He described sections on the Peace river between Little Rapids and Peace Point, at La Butte, Stony Island, Salt River, and other places. By means of the fossils he collected he was able to state that "the whole area is underlain by sedimentary rocks of middle Devonian age, which rest on a floor of Precambrian granite."

In the Peace River sections the exposed maximum thickness of gypsum is 50 feet. Overlying the gypsum is fractured dolomite (10 to 30 feet) and limestone and then drift (5 to 20 feet.) The distinctive features of these deposits are the presence of anhydrite, the broken and fragmental overlying dolomite, the disturbed character of the gypsum and the fossils

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*Camsell, C.: Geol. Surv. Can., Summ. Rept. 1916, p. 134.

found which indicated a horizon of middle Devonian age.

The La Butte sections show beds of undulatory character with some fracturing and with dips up to 15°. The section from the bottom up is as follows:

		Feet.
(1)	Thin-bedded, grey limestone	10
(2)	Brecciated limestone impregnated with bitumin	6
(3)	Pebbly limestone	10
(4)	Massive limestone containing fossils	5

Ten feet of gypsum occurs showing thin bedded and impure qualities.

The Stony Island sections show the following succession from the bottom up:

		Feet.
(1)	Coarse grained porphyritic granite	?
(2)	Conglomerate passing to sandstone	8
(3)	Dark grey, dolomitic limestone passing to light-colored massive limestone	?

Although no section was obtainable from Salt River about 50 feet of impure gypsum is exposed at one place. Salt was found in association with the gypsum on this river southwest of Fitzgerald.

Later and more detailed work including sampling was carried out on the Peace River deposits by A. E. Cameron* in 1928.

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*Cameron, A. E.: Research Council of Alberta, Rept. No. 25, 1929, p. 41.

One of his sections which was taken on the north side of Peace river at Peace Point is as follows:

		Feet.	In.
(1)	Surface till and glacial clays	2	
(2)	Brecciated dolomite	18	
(3)	Thin bedded grey gypsum	9	6
(4)	Massive white to light grey gypsum with thin stringers of fibrous gypsum parallel to and cutting massive beds	6	
(5)	Massive white saccharoidal gypsum	3	4
(6)	White gypsum with lenses of grey anhydrite	3	3
(7)	Massive white to grey gypsum to river level	10	

Bottom not exposed

General Geology.

In nearly all of the Palaeozoic outcrops of the area gypsum occurs. In those outcrops where gypsum does not occur its presence is suspected by the pitted and broken nature of the surface.

Camsell* describes the deposits as follows:

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*Camsell, C.: Geol. Surv. Summ. Rept. No. 26, 1914, pp. 139-140.

"On Peace river gypsum is exposed on both banks of the river almost continuously for a distance of 15 miles or from Little rapids to a point 5 miles below Peace point. The exposed thickness varies from a few feet up to a maximum of 50 feet, the latter occurring on the south side of the river at the foot of the rapids. The gypsum is usually white and massive. In places it is earthy and thin bedded or holds narrow bands of dolomitic limestone. Selenite is rare, but thin veins and beds of satin spar are common. Anhydrite is occasionally present in rounded nodules or in thin

beds. Overlying the gypsum is a fractured and broken bed of limestone, but since the structure of the beds is undulatory the gypsum is frequently brought up to the top of the cliffs and has no cover except the drift, the limestone having been removed by erosion. The drift varies in thickness from 5 to 15 feet and when the gypsum is covered only by the drift the conditions are most favourable for the economical mining of the beds. Such conditions occur in a number of localities in the section, particularly on the north side of the river.

"Judging by the character of the surface back from the face of the cliff, gypsum must extend back from the river for a considerable distance. Taking an exposed length of 15 miles along the river and an average thickness of 15 feet of gypsum and assuming that the beds extend back from the river for at least a distance of a quarter of a mile on either side of the river, the quantity of gypsum in the Peace River section is at least 217,000,000 tons. A considerable proportion of this is very favourably situated for mining on account both of its location and the thin overburden of drift."

Cameron* makes special note of the fact that the character of the gypsum changes laterally. To quote him: "Given horizons of beds can be traced in a few hundred feet, from a dense, hard, white to grey, thin-bedded material, to a coarse, soft, massive, saccharoidal type."

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*Cameron, A. E.: Research Council of Alberta, Rept. No. 25, 1929, p. 43.

Economic Possibilities.

After studying the area Cameron came to the conclusion that Camsell's estimate of 217,000,000 tons of gypsum could be increased to five times that amount. Much of this gypsum, lying very close to the surface as it does, could be mined quite easily. The main problem in connection with placing the material on the market is the transportation problems. The cost of river transportation by means of scows to rail-head at Waterways would be in the neighborhood of $2.50 per ton of gypsum. Additional steamer and railway costs would bring the total cost of transportation to Edmonton to about $8.00. To compete successfully in the Edmonton market the price of the finished product would have to be as low as the price of the Manitoba and British Columbia products. Since calcining costs would be much the same in all cases the chief hindrances to the exploitation of the Peace River deposits are those of costs in transportation.

Origin of the Gypsum Deposits on the Peace River.

The Peace River deposits, as was the case with the Jasper Park deposits, exhibit certain features by means of which we are able to make fairly definite statements with regard to their origin. Little can be said that would alter Cameron's* conclusions. The main features of the deposits brought out by him in substantiation of Camsell's reconnaissance work were:-

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*Cameron, A. E., Geol. Sur. Can. Summ. Rept. 1921, pt. B., p. 33.

(1) The gypsum varied in appearance from a white, hard, massive type to an earthy, thin-bedded variety.

(2) Presence of anhydrite within the gypsum.

(3) Sedimentary banded nature of the deposit.

(4) Gentle folding of the sedimentary beds, with no uniformity in the direction of strike of the folds.

(5) Fractured and brecciated overlying limestone beds.

(6) Presence of thin beds of satin spar and some selenite.

(7) Marine association.

The general conditions of the Peace River deposits represent a duplication of the Jasper Park deposits in that the deposits show marine association and a depositional character of the sedimentary type. Farther than this the deposits do not coincide. The story of the formation of the Peace River deposits probably shows a different development.

No evidence can be found for considering the deposit as having been formed by the chemical alteration of sedimentary limestone. No evident source for acid sulphate solutions can be found. More specifically, nothing within the deposits, such as residual blocks, irregular contacts, or alteration phases of limestone can be found to substantiate the viewpoint. In this respect, then, the deposits resemble the Amaranth deposits of Manitoba.

The deposit then falls within the general classification

of a sedimentary deposit for in these deposits the amount of gypsum is again too great to have been derived from disseminated material. In contrast to the Jasper Park deposits these deposits contain anhydrite and, to follow the reasoning used for the Jasper Park deposits, the solutions in the residual basin or basins must have become sufficiently concentrated to deposit salt. The theory that anhydrite was the original form of the deposit is substantiated by several strong criteria. It must be remembered that such criteria are applicable only to the visible portions of the deposits and nothing can be said definitely of the lowest beds of the deposit. In the opinion of the writer the deposits at depth probably contain gypsum derived from direct precipitation.

To come back to the criteria which favor the theory that the main portion of the deposit has been formed by the hydration of anhydrite; these are, briefly:

(1) The presence of rounded cores of anhydrite. These cores represent the remnants of the former anhydrite deposits.

(2) The presence of a rim on the anhydrite cores showing alteration from anhydrite to gypsum.

(3) The absence of any overburden sufficient to hinder the alteration.

(4) The disturbed character of the overlying sedimentary beds.

The character of these beds indicate in several ways that the disturbance was caused by the expansion of the underlying sulphate deposits when they took on water to form gypsum. Such an addition of water to form gypsum would cause an increase in volume of 33 percent. The variations in the amount of dip and the irregular direction in strike of the folds would not seem to indicate that they were formed by an orogenic movement but rather that each fold resulted from a local pressure.

(5) The presence of anhydrite as thin beds would, if nothing else, prove that anhydrite was deposited as such in the deposit. No sufficient overburden could be justifiably postulated to have caused the alteration of gypsum to anhydrite.

With these factors favoring the deposit as being a result of the hydration of anhydrite, it seems fairly reasonable to consider the deposit as such. There are certain other features of the deposits, however, which should be discussed in relation to their possible effect on the origin of the deposits.

The deposits characteristically show a change in appearance and physical character. The beds have been noted as changing from a "dense, hard, white to grey, thin-bedded material, to a coarse, soft, massive, saccharoidal type" in a few hundred feet. Cameron has attributed this difference to variations in the silica content. This undoubtedly is of great importance in

explaining the presence of saccharoidal gypsum since the saccharoidal texture is generally considered to be associated with arid conditions and under such conditions it would be hard to explain its presence in a deposit formed by the hydration of anhydrite. Other variations are probably due to differences in the rate of hydration, differences in the amount of overburden and original differences in the physical character of the deposit.

Very characteristic of a deposit formed by hydration from anhydrite are the complicated bedding contortions due to expansion pressures. This phenomenon, although it has been noted in associated beds (Field Notes by A. E. Cameron) seems to be rare within the deposit. This has been explained by Cameron (oral communication) at least for particular instances. Gypsum derived from massive anhydrite would have no bedding planes which would show in the altered phase. This however does not explain the many instances of thin gypsum bands. If the major amount of hydration took place on the under surface of the deposit upheavals and broad warpings would be produced. Later hydration of overlying beds would tend to accentuate the warping and since the overlying sediments would have been broken hydration would continue more evenly and reduce the chances for contortions in the gypsum beds.

The maximum thickness of 50 feet in the deposit would represent a greater thickness than the original anhydrite thickness but would still have to be explained according to Branson's theory for thick gypsum deposits.

In the final analysis the conditions of the deposit best suit the theory that they have been formed by the hydration of sedimentary anhydrite.

MCMURRAY DEPOSITS

Introduction.

The presence of gypsum in the McMurray district has been determined through well drillings, there being no outcrops of gypsiferous rocks in the area. This discovery was really incidental to oil and salt investigations in the area. The best records were obtained in the provincial salt wells. Under recommendations from Dr. J. A. Allan, the Alberta Provincial Government sunk one test well in the townsite of McMurray, section 21, township 89, range 9, west of the 4th meridian, during the seasons 1919 to 1920. This well was drilled with a rotary Davis Calyx drill to a depth of 685½ feet.

In order to determine the lateral extent of the salt beds as encountered in the test well at McMurray a second test well was sunk. The well was located by Dr. Allan six miles east of McMurray at the then terminus of the Alberta and Great Waterways Railway. This well, now known as Well No. 2, was drilled under the direction of the Provincial Mines Branch with the same rotary Davis Calyx tools used in Well No. 1. The depth in

this case was carried to 789 feet.

Geology of the McMurray Deposits.

The geology of the McMurray deposits, other than surface geology, has been determined through a study of the salt-well cores. R. G. McConnell* reported on the succession on the Athabaska between McMurray and Athabaska Landing. This succession was given as:-

	Feet
La Biche shales	900
Pelican sandstone	40
Pelican shales	90
Grand Rapid sandstone	300
Clearwater shale	275
Bituminous sands	0 to 200
Devonian limestones	30
Bottom not exposed.	

A long erosion period occurred between the Devonian limestone and the bituminous sandstone.

Any further knowledge of the geological section is dependent on well cores. Warren* examined and determined fossil specimens from the drill-cores and used them to find the age of the series. Fossils were determined from depths of 95 feet to 500 feet below which no fossils were observed. To quote Dr. Warren: "It is

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*McConnell, R. G.: Geol. Sur. Can. Ann. Rept., Vol. V., Pt. D., 1890-91, pp. 27-62.

*Warren, P. S.: Research Council of Alberta, Rept. No. 2, 1920, p. 113.

difficult to determine the age of this fauna on account of some of the species being new and the lack of good horizon markers. I would place it in the upper Devonian for the following reasons:-

(1) The presence of Lingula spatulata

(2) The resemblance of this fauna to that obtained in the upper Devonian as developed in Hay River, some of the fossiliferous bands being absolutely identical.

(3) The entire absence of the typical middle Devonian fauna as developed on Great Slave lake."

Logs of both wells have been worked out by Allan*. This includes a description of the beds which have been placed by Warren in the upper Devonian and the underlying beds including gypsum and anhydrite. In Well No. 1 neither gypsum nor anhydrite occur above a depth of 500 feet and in Well No. 2 no gypsum was encountered till a depth of 415 feet was reached. This is of significance in regard to the theory of zonal distribution and is discussed in the section on the origin of the McMurray gypsum deposits. Certain horizons in the two wells can be directly correlated. By means of this correlation it was determined that there is a rise of approximately 95 feet in the formation towards the east. As was determined by means of the well at Waterways

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*Allan, J. A.: 2nd Ann. Rept. on the Mineral Resources of Alberta, 1920, p. 106.
4th Annual Rept. of the Scientific and Industrial Research Council of Alberta, 1923, p. 50.

gypsum was found to occur practically on top of the pre-Cambrian granites.

The McMurray deposit, in contrast to the Jasper Park deposit shows anhydrite in association with the gypsum. Thin beds of banded gypsum and anhydrite are common, as can be seen from the well sections included herein. Massive beds of both minerals also occur. Of the sedimentary beds included, limestones and dolomites are the most important with shale in less amounts. Limestone, though present in Well No. 1 and 2 above the gypsum is peculiarly absent from them in the gypsum series. The dolomite in many cases carried selenite lenses and salt cavities. Throughout the section gypsum occurs in a variety of modes. Some of these are: massive gypsum, fibrous gypsum, thin bedded gypsum bands, mottled gypsum, vein gypsum and as gypsum lenses. Various colors also occur such as pink, white, grey and bluish. At the bottom of Well No. 2 the gypsum occurs with many angular grains of quartz.

Age of the Deposit.

As has been noted, the limestone beds overlying the gypsum deposits have been determined as upper Devonian. Kindle* described a section 80 miles above the mouth of Peace river containing gypsum, anhydrite and magnesium limestone. Although fossils were very scarce and occurred only in the uppermost beds of the section he

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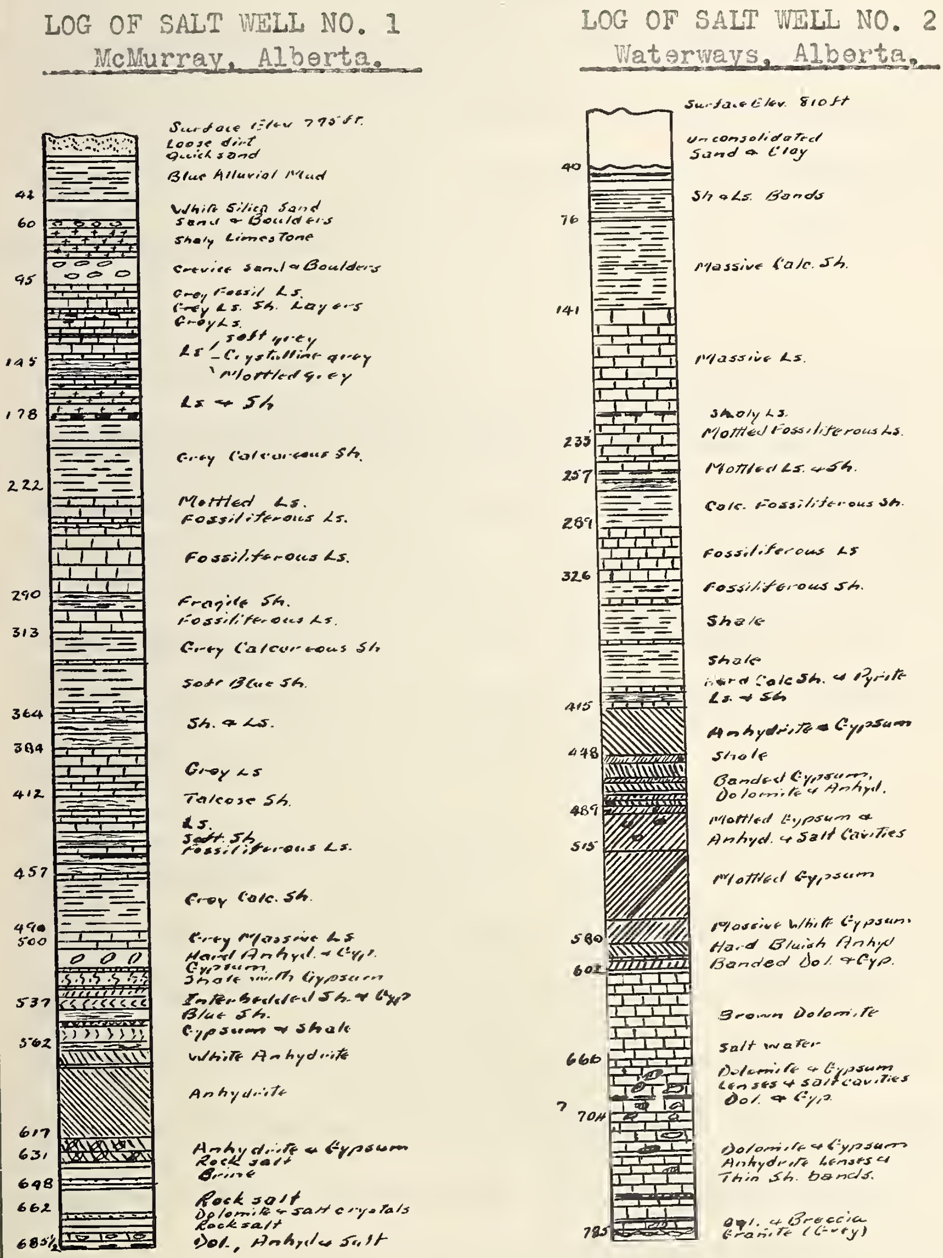
*Kindle, E. M.: Geol. Surv. Can. Mus. Bull. No. 49, 1928, p. 14.



LOG OF SALT WELL NO. 1
McMurray, Alberta.

LOG OF SALT WELL NO. 2
Waterways, Alberta.

Figure No. 13. Columnar sections Gypsum Deposits at McMurray and Waterways. (Compiled by J. A. Allan.)

was able to place the horizon as late Silurian by means of the fossils Spirifer crispus (Hisinger), Modiolopsis sp., Modiclopsis sp. cf. orthonata (Conrad). If, then, the deposits can be correlated with the McMurray deposits, the McMurray deposits are of upper Silurian age. This corresponds to the lithological correlation which has been advanced between the Manitoba and McMurray deposits.

Later work by Warren* established the correlation between the limestone beds on the Athabaska river at McMurray and the Devonian beds at Peace Point as described by Kindle. This, then, establishes the position of the McMurray gypsum since it underlies the limestone series which Warren has named the Waterways formation and the gypsum is upper Silurian in age.

Origin of the McMurray Deposits.

The general conditions of the McMurray deposits comply with general conditions as evidenced in the Peace River deposits. Gypsum and anhydrite are found interbedded with dolomite. This close association of the sulphate deposits with the dolomite leads us directly to a consideration of the deposits as being derived from solution. The complications arising from such a theory will be dealt with first.

The thickness of gypsum in the deposit does not represent

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*Warren, P. S.: Can. Field Naturalist, 1933, p. 148.

quite the problem that it might at first appear to. The thickest single bed of gypsum as obtained in Salt Well No. 2 is 48 feet and this is but a single instance. The remainder of the gypsum and anhydrite beds do not exceed 17 feet. These bands are characteristically separated by dolomite. The deposits thus appear to have been formed in marginal saline basins. They could easily be considered as the type described by Oschenius or Branson. The purity of the beds favors Branson's modified theory.

The physical appearance of the dolomite represents a problem closely connected with this depositional theory. In some cases the dolomite is thin-bedded and conformable with the interbedded gypsum or anhydrite layers. In other instances it is massive. The dolomite in the former case appears to have been a result of ordinary sedimentary deposition; in the latter the character of the material suggests a ready supply of dolomitic material from the surrounding land areas. An added source of the magnesium in the dolomite would be from the concentration of magnesium sulphate in the saline waters. Such an action would involve the reaction of the magnesium sulphate solutions with calcium carbonate to form calcium sulphate and calcium magnesium carbonate. It seems reasonable to expect such a reaction to take place previous to the deposition of calcium carbonate rather than considering an alteration of the deposited calcium carbonate by the leaching action of the magnesium sulphate solutions. This

gives a possible explanation of the presence of dolomite in the gypsum series. The amount of magnesium necessary for such a reaction represents the main point of doubt.

The thin-bedded sedimentary dolomite apparently received its source of magnesium from the concentrated solutions. The depositional sequence as shown by the drill cores fit in well with this theory. The supply of carbonate material can most easily be explained as having been derived from a fresh supply of saline water. Under such conditions the deposit appears to have been formed along the margins of an undulatory sea-coast.

The next striking feature of the deposit is the fact that it lies directly on pre-Cambrian granites. The ten feet of sediments lying directly on the pre-Cambrian granites show angular quartz with a gypsum matrix grading into gypsum containing angular quartz grains. Such a condition indicates a near-shore condition and accentuates what has been said in the preceding paragraph. If the topography resembled in any way the topography of the pre-Cambrian shield of present times conditions would be suitable for the deposition of gypsum according to the theory of Oschenius or the modified theory of Branson. Large sedimentary basins capable of being filled with saline waters and of retaining such solutions would be present. A slowly advancing sea would force ahead of itself a margin of concentrated water. These concentrated solutions would form the mother liquors of the sulphate deposits. A period of recession in the general advance of the sea would

serve as a period of concentration and possibly deposition of the calcium sulphate.

These conditions, though they necessitated an explanation, conform with the theory of sedimentary deposition. Other factors which are more evident also favor the sedimentary theory of origin. Some of these are: (1) the wide lateral extent of the deposit, (2) the thickness of the deposit, (3) the mineral associations of anhydrite and halite, (4) the banded appearance.

Considering, then, the deposit as having been formed by the concentration of saline waters the problem arises concerning the primary or secondary nature of gypsum and anhydrite. The deposit shows a close association of gypsum, anhydrite and salt. In the presence of a solution concentrated with respect to salt and temperatures favorable for rapid evaporation, anhydrite would be the stable depositional form. In the first stages of deposition; i. e., when the temperature was lower, gypsum might be the depositional form for the calcium sulphate. Such is evidently the case in the McMurray deposits. Primary gypsum and primary anhydrite are present. Secondary gypsum derived from the hydration of anhydrite is also present as shown by the contorted banding of some of the gypsum.

The circumstances under which secondary gypsum could have formed are in some respects restricted. Primary gypsum and anhydrite would necessarily be formed at the time of deposition. Secondary gypsum would be formed later in the history of the deposit and under conditions most favorable for its development. Such con-

ditions would involve a ready supply of water and a small pressure from overlying sediments. The deposits, at depths to which they are now buried, probably have but a small supply of meteoric water and are under such pressures that secondary gypsum could not form. Secondary gypsum can, then, best be considered as having been formed when the sulphate deposit lay close to the earth's surface.

In this respect the McMurray deposits represent a strong divergence from the theory of zonal distribution. The deposits lie at depths well below the gypsum zone postulated by Newland* and yet gypsum is prevalent at such depths. The deposits fall more in line with the theories advance by Wallace*. Pressure has evidently had no effect in the alteration of the deep-seated gypsum to anhydrite.

Although the theories heretofore discussed represent the mode of origin which the writer holds for the main deposit there are several features worthy of note which may be taken as indications of different origin. The first of these features indicates that the deposit may have been formed by the action of acid solutions on calcium carbonate. Lying above the gypsum deposit at a depth of 400 feet in Well No. 2 is a seven foot bed of hard calcareous shale containing pyrite. This pyrite may be thought of as the remnants of a source of sulphate solutions. Several reasons, however, may be advanced against such theory. No iron stains are

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*Newland, D. H.: Ec. Geol., Vol. 16, 1921, p. 400.

*Wallace, R. C.: Geol. Mag., 1914, p. 271.

present below the shale bed and in the gypsum series. The bedded and widespread character of the deposits. The presence of anhydrite itself prohibits the retention of such a theory unless we are to consider that the anhydrite has been formed by the dehydration of gypsum. The acid solutions, since they contain water, would form the sulphate as gypsum rather than anhydrite. The absence of such a pyrite bed above the gypsum in Well No. 1 lessens the possibility still farther for such a theory. It seems evident then that the theory of alteration of limestone cannot apply to the McMurray deposits.

The size and extent of the deposits alone prohibits them being considered as derived from the concentration of disseminated materials by action of surface waters or winds. Minor occurrences of fibrous gypsum in fissures or cavities within the main sulphate beds may, however, be considered on such a basis. Small stringers of fibrous gypsum or selenite which appear to be filling fissures or cracks of bedding planes are quite common in the deposit. Such occurrences can best be explained as secondary deposition of gypsum from solution. The cracks and fissures are evidently structural cracks or jointing cracks. Into these openings solutions carrying calcium sulphate have passed and deposited the gypsum in the form of selenite or fibrous gypsum. The source for such sulphate solutions is purely conjectural and we can but consider the different possibilities.

The solutions have evidently come from above and the source must be taken as being above the position of the vein in question. Two evident sources come to mind. The overlying gypsum itself would be a very probable source. Such gypsum would have to be dissolved in solutions, acid or otherwise, and redeposited in the lower lying fissures. As well as this the calcium sulphate still contained in overlying concentrated saline solutions might be a source for the veined gypsum.

The relative importance of the two theories can be estimated only by the conditions which present themselves as favorable or unfavorable for one theory or the other. The chances for overlying concentrated saline solutions being the source are minimized by the fact that no salt is found in association with the veined gypsum. Crustal movement would also have had to occur in a relatively short time to form the fissures for deposition. Other than this bedding planes and jointing cracks would represent the only available openings.

F. A. Wilder* considers these veins to be secondary concentrations. The factors in favor of this are: a ready supply of gypsum in the overlying beds which could be concentrated in the fissures; a greater length of time in which crustal movements could produce fissures. The problems connected with such a secondary concentration are the methods by means of which the gypsum is

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*Wilder, F. A.: Iowa Geol. Surv., Vol. 28, 1917-18, p. 125.

taken into solution, transported and reprecipitated. Solution might have been affected by the action of aqueous or acidic solutions, which solutions would in turn supply the transporting medium for the gypsum. The re-deposition of the gypsum would probably be caused by the action of external agencies. An increase in pressure would conceivably affect the stability of the aqueous gypsum solution. An increase in temperature would occur with depth but this would probably be too small to have an effect on the solution. Absorption of water from the solution as it passed through anhydrite beds or finely porous dolomite beds would tend to concentrate the solutions. Whatever the actual cause for the re-deposition of the gypsum, the physical attitude of the vein deposits is best explained as secondary concentrations.

Such vein occurrences are not to be confused with the numerous small gypsum lenses which are found in the dolomite beds. These are best expressed as minor concentrations of gypsum formed during the deposition of dolomite beds.

In general conclusion to the discussion of the origin of the McMurray deposits it may be said that the deposit can be classified most easily as one derived from the concentration of saline waters. Primary gypsum and primary anhydrite occur. Secondary gypsum, derived from the alteration of anhydrite is also present. Secondary concentrations of gypsum occur as fissure and vein deposits in the main gypsum mass.

The primary gypsum is probably represented by such types as massive and fibrous banded gypsum. Although it may show a close association with anhydrite it is more likely that salt will not show a contiguous occurrence. Such is the case with the horizons of this type as tabulated in the sections given for the McMurray deposits in the following chapter. The anhydrite deposits, in the writer's opinion, in all cases represent a primary occurrence.

The secondary deposits of gypsum are characterized by an indigenous association with anhydrite or a vein occurrence. Mottled gypsum and anhydrite masses are good examples of such an indigenous occurrence. Folding in the gypsum bands, unless it is the result of orogenic movements, may be taken as indicative of a secondary deposit. Vein occurrences as has been definitely noted can best be expressed as secondary deposits.

CHAPTER VI

DETERMINATIONS ON GYPSUM SAMPLES

General Statement.

In the study of the Alberta deposits it was necessary to determine the character of the representative specimens of the various deposits. These specimens, which have been collected and kept for reference in the Department of Geology of the University of Alberta, consist chiefly of suites from the Jasper Park and Peace River deposits and well cores from the McMurray deposits. Although general determinations have been made by J. A. Allan it has been the purpose of the writer to make a more detailed study upon which to base the conclusions derived for the origin of the deposits. The work carried on is described below.

Determinations on the samples from Jasper Park.

The samples collected from the Jasper Park deposits and which were studied by the writer included typical specimens of gypsum and associated rocks. The associated rocks were studied on a physical and chemical basis in order to determine their composition and possible significance to the gypsum deposit. The pertinent features of the gypsum itself were its type, texture, structure and composition.

The deposit has been noted as containing no anhydrite. This was determined by examining the gypsum in crushed sections with

the aid of a petrographical microscope. Anhydrite and gypsum can be differentiated by means of their refractive indices. Since anhydrite has an index of 1.57 to 1.61 and gypsum an index of 1.52 to 1.53 they can be differentiated in an immersion solution of index 1.54. The impurities of $CaCO_3$ in the samples were removed by acid action, care being taken not to heat the sample since the gypsum might then be dehydrated to anhydrite. In all the samples of this deposit so examined no anhydrite was found.

The gypsum occurs in a variety of forms and each form shows a certain significance relating to the way in which it was formed. These types are listed below with a description and note on the significance of each.

Gypsum specimens from McDonald Gulch:-

(1) Gypsum, grey, crystalline, uneven texture with cavities. This specimen is an example of the impure type of gypsum found in the deposit. The cavities are probably the result of the removal of included sedimentary calcium carbonate.

(2) Gypsum, white, crystalline, and dolomite, grey. The gypsum is interdispersed with dolomite as a fragmental mass. The type has probably been formed by the crushing and fracturing of a banded dolomite and gypsum rock.

(3) Gypsum, grey, coarse thick-bedded, uneven texture, containing rounded quartz grains and dolomite in small amounts. The dolomite occurs as inclusions and suggests a depositional origin. The rounded quartz grains suggest an association of arid conditions

or conditions of shallow deposition. Some of the gypsum in the specimen is white and pure.

(4) Finely crystalline and banded pure and impure gypsum. Folding occurs in the bedding. A coarsely crystalline type of gypsum occurs in association with fractured dolomite, giving the impression that the dolomite was crushed and the gypsum deposited subsequent to the crushing. The presence of selenite indicates the action of aqueous solutions as depositional agents.

(5) Gypsum, white, bedded, massive and crystalline. This specimen is representative of gypsum derived from direct precipitation from saline waters.

(6) Gypsum, white, crystalline, showing pure bands with grey to brown impure interbanding material.

(7) Gypsum, white, saccharoidal. Taken from upper part of the gypsum bed. Dark, irregular bands are suggestive of wind action.

(8) Gypsum, impure, finely mottled with grey limestone. Type occurs in the beds of the upper gypsum series.

Gypsum specimens from Corser Gulch:-

(1) Gypsum, grey massive. This specimen shows pitting due to erosive action.

(2) Gypsum, white to grey, coarsely crystalline to medium. The bands show folding. One specimen contains dolomitic inclusions, the dolomite again being depositional.

General typical gypsum specimens:-

(1) Gypsum, white, banded, showing folded structures. (see

frontispiece.)

(2) Gypsum, white, pure finely crystalline, fine uneven banding. The specimen was taken from near the top of the gypsum section as illustrative of the lensy character of certain parts of the deposit.

(3) Gypsum from gypsum horizon on the Athabaska valley:

(1) Quartzite, fractured, with saccharoidal gypsum in the fissures formed by infiltration.

(2) Yellow gypsum rock, fine to medium crystalline. Color is caused by yellow iron oxide impurities. The gypsum also occurs as veins and bands.

Associated rocks of the Gypsum Deposits.

The rocks associated with the gypsum include such types as limestone, dolomite, shale, sandstone and quartzite. These are described below:-

Limestone specimens:-

(1) Limestone, red, coarse, porous, uneven texture, containing rounded quartz grains. Is typical of the Red beds overlying the main gypsum series.

(2) Limestone, white to grey, broken and fragmental. Particular specimen shows an early stage in weathering processes. Sample comes from the upper gypsum series.

(3) Limestone, grey, hard, with some cavities, possibly caused by the dissolving of included gypsum. The specimen is typical of

the top beds of the measured section.

(4) Limestone, grey, fine-grained, finely mottled with impure gypsum. This type occurs in the upper gypsum series.

The limestones towards the top of the measured section characteristically show weathering to a latticed structure. Yellow limestone lenses which show weathering action occur below the upper gypsum bed. The angular cavities in many of the limestones are probably due to differential weathering of the rock material or to the dissolving of included gypsum lenses.

Dolomite specimens:-

The associated dolomite rocks characteristically occur but in small amounts and in these cases are in direct association with gypsum. In some cases the limestones appear to be somewhat dolomitic. Two specimens were studied:

(1) Dolomite, dark grey, fragmental, occurring interdispersed with white crystalline gypsum.

(2) Dolomite, grey, finely banded with hard limestone. From the upper gypsum bearing series.

Shale specimens:-

The shale specimens which were studied were in all cases quite calcareous. They are grey and calcareous and usually finely banded. In some cases they grade towards a thin bedded shaley limestone.

Sandstone specimens:-

The sandstone as found in the gypsum horizon on the Athabaska valley is grey and massive showing bedding planes and jointing cracks. The sandstone which occurs at the base of the McDonald Gulch section is coarse, yellow and massive with calcium carbonate as its binding material. A fine grained calcareous sandstone with a saccharoidal texture occurs in the upper Buff series.

Determinations on the samples from Peace River.

A few samples typical of the gypsum at Peace River were available for study. The various types are included in the following list of descriptions:-

(1) Gypsum, white, massive, showing surface pitting due to erosion.

(2) Gypsum, white, massive, pure, associated with brownish dolomitic limestone.

(3) Gypsum, white with irregularly banded buff colored dolomite.

(4) Gypsum, transparent, coarsely crystalline intermixed with grey calcium carbonate.

(5) Gypsum, coarse crystalline, impure.

(6) Gypsum, white and brownish, crystalline, impure.

(7) Gypsum, white and brownish, massive, with gypsum stringers.

(8) Gypsum, buff and brown, impure banded. Banding is shown up by differential erosion.

(9) Gypsum, grey, impure, irregular banding, surface pitting due to erosion.

Determinations on the McMurray and Waterways well cores.

The general logs of both the McMurray and Waterways well cores have been done by J. A. Allan.*

The writer has worked out a more detailed log of the parts of the wells that are most significant to this thesis, that is, the parts containing gypsum and anhydrite. The sections with depths and intervals of occurrence are given below:

A DETAILED LOG SECTION OF THE GYPSUM AND ANHYDRITE ZONES OF SALT WELL NO. 1, McMURRAY, ALBERTA.

	Thickness		Depth	
	Ft.	In.	Ft.	In.
Limestone, grey, dolomitic, fractured.	1		501	
Limestone, dark grey, banded.	1		502	
Limestone, light grey, dolomitic with gypsum stringers and a 2" white gypsum band.	1		503	
Gypsum, white, and anhydrite, brown, banded.	9	6	512	6
Shale, grey, siliceous, and gypsum.	1	6	514	
Limestone, light brown, thin bedded and gypsum stringers.	2		516	
Limestone, grey	1		517	
Anhydrite, grey and interbanded fibrous gypsum.	3		520	
Shale, grey, calcareous, with interbanded fibrous gypsum and gypsum lenses.	3		523	
Gypsum and anhydrite, interbedded with some grey shale. Gypsum veins and stringers common.	2		525	
Gypsum, blue, fibrous and anhydrite interbedded with shale.	1		526	
Gypsum, anhydrite and shale, finely banded.	1	6	527	6
Anhydrite with gypsum stringers and bands. Shale in small amounts, decreasing with depth.	7		534	6

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*Allan, J. A.: Research Council of Alberta: Rept. No. 2, 1920, p. 107. Rept. No. 10, 1923, p. 50.

	Thickness Ft.	Thickness In.	Depth Ft.	Depth In.
Gypsum, blue, lensy.		6	535	
Dolomite, grey, with anhydrite and gypsum stringers and lenses.	5		540	
Shale, greenish grey, with pink gypsum bands.	1		541	
Dolomite, grey, massive.	4		545	
Dolomite, buff, interbedded with fibrous gypsum.	1		546	
Gypsum, pink, thin bedded, with shale.	2		548	
Shale, greenish grey and dolomite, brownish, with pink gypsum bands.	2		550	
Shale, thin bedded with gypsum and dolomite.	3		553	
Dolomite, buff to grey, with gypsum stringers.	5		558	
Shale, brown.	2		560	
Dolomite, dark grey, massive.	3	6	563	6
Anhydrite, grey to white with some gypsum.	1	6	565	
Dolomite or dolomitic limestone, buff thin bedded, with bluish gypsum lenses.	5		570	
Dolomite, buff and shale, grey, calcareous with gypsum lenses.	1		571	
Gypsum, bluish, mottled with shale.	1		572	
Anhydrite	1		573	
Gypsum, lenses and stringers in greenish grey calcareous shale with red and brown stains.	1		574	
Gypsum, bluish and white with red stains in stringers.	1		575	
Gypsum, white and anhydrite, red and blue in grey calcareous shale.	4	6	579	6
Gypsum, impure, 4" lense in contact with a small pebble horizon and calcareous shale.		6	580	
Anhydrite, grey.	1		581	
Gypsum, greyish white.	1		582	
Anhydrite, grey	1		583	
Anhydrite with greenish grey calcareous shale and red stains.	2		585	
Anhydrite		6	585	6
Anhydrite with green grey shale		6	586	
Gypsum and anhydrite, mottled with shale impurities and some fibrous gypsum bands.	2		588	6
Anhydrite with dark green shale interbanded.	5	6	594	
Anhydrite and buff colored dolomite intermixed.	1		595	
Anhydrite and shale		6	595	6
Shale, greenish, calcareous with gypsum lenses.	1	6	597	
Anhydrite, dark grey, massive.	5		602	

	Thickness		Depth	
	Ft.	In.	Ft.	In.
No core, washings.	3		605	
Anhydrite, blue, massive, dolomitic impurities mottled with gypsum in lower two feet.	14		619	
Anhydrite with shale.	1		620	
Anhydrite, grey with some gypsum.	5		625	
Limestone, buff, dolomitic.	1		626	
*"No core, washings saline	1		627	
"Anhydrite and gypsum with salt crystals.	4		631	
"Porous granular core, largely rock salt.	4		635	
"Hard Anhydrite	1		636	
"No core but washings saline, specific gravity of brine 1.09	5		641	
"Granular porous mass, salt and anhydrite	4		645	
"No core but the saturated brine, specific gravity 1.23 (4-3/4 pounds of salt evaporated from 2 imperial gallons of brine.)	3		648	
"Rock salt, transparent and colorless."	14		662	
Anhydrite, grey, finely crystalline, thin bedded, with salt.	3		665	
Gypsum, white fibrous, bedded with shale.	1		666	
Anhydrite and dolomite.	1		667	
No core, salt fragments.	7		673	
Gypsum and shale, impure.	1		674	
Anhydrite and rock salt.	1		675	
Shale, dark grey.	1		676	
Dolomite with salt.	3		679	
Dolomite, grey, massive.	1		680	
Anhydrite, coarse, granular.	2		682	
Anhydrite, compact, finely crystalline.	3	6	685	6
Bottom of well.				

*Due to the incompleteness of the well core data for the interval between depths of 626 feet and 662 feet have been taken from J. A. Allan, Research Council of Alberta, Report No. 2, 1920, p. 108.

A DETAILED LOG SECTION OF THE GYPSUM AND ANHYDRITE ZONES OF SALT WELL NO. 2, WATERWAYS, ALBERTA.

	Thickness		Depth	
	Ft.	In.	Ft.	In.
Anhydrite and gypsum, banded.	5		420	
Anhydrite, dark grey, massive.	7		427	
Anhydrite, with thin banded gypsum and shale.	14		441	
Anhydrite, grey, massive, with gypsum veins.	4		445	
Shale, grey, calcareous, banded with gypsum. Fibrous 1½" gypsum stringers.	2	6	447	6
Shale, greenish grey with irregular 1½" veins of gypsum at 449'.	2	6	450	
Shale, red brown interlaminated with green grey, finely banded. Beds show a noticeable dip.	1	6	451	6
Shale, grey calcareous containing 1/4" veins of blue and white coarsely crystalline gypsum.	1	6	453	
Dolomite, pinish, banded, containing small irregular stringers of gypsum.	1		454	
Shale, greenish grey with an occasional stringer of gypsum.	4		458	
Shale, greenish grey, soft.	6		464	
Gypsum, pink and blue, 1/4 " bands, with green shale.		6	464	6
Gypsum, banded, folded in grey shale.		6	465	
Dolomite, buff colored, massive.	1	6	466	6
Dolomite, banded with grey grey shale.		6	467	
Dolomite, grey to buff, coarsely crystalline with banded gypsum and anhydrite.	3		470	
Dolomite, light grey, fine grained, with irregular bands of gypsum.	2		472	
Anhydrite with gypsum and some dolomite.		6	472	6
Shale, greenish grey, with brown stains, white powdery gypsum and bluish stringers.	1	6	474	
Dolomite, grey, with occasional stringers of pink gypsum.	2	6	476	6
Shale, greenish grey, highly calcareous with brown stains, gypsum stringers.	3	6	480	
Gypsum, fibrous banded with shale.		6	480	6
Dolomite, crystalline, and shale, greenish grey calcareous with brown stains.	1	3	481	9

	Thickness		Depth	
	Ft.	In.	Ft.	In.
Micaceous schist or sandstone.		6	482	
Anhydrite, grey to brown, crystalline, massive and thin bedded with pink gypsum bands. Shale bands occur at 485'	4	6	486	6
Shale, greenish grey with gypsum lenses.		6	487	
Anhydrite, massive, with gypsum bands and some shale.	1		488	
Gypsum, impure mottled, with greenish grey calcareous shale.	3		491	
Gypsum, mottled, with anhydrite	1		492	
Gypsum, mottled, with shale, contorted bands.	1		493	
Gypsum, mottled, pale blue, grading from finely crystalline to coarse with depth.	1	6	494	6
Gypsum and anhydrite, with grey calcareous shale.	2		496	6
Anhydrite	1	6	498	
Gypsum, grey, with shale.	4		502	
Anhydrite, massive with some banded gypsum and shale.	12		514	
Gypsum and anhydrite, with impure shaley bands. at 517' and 520'.	12		526	
Gypsum, blue, massive, with occasional bands of light grey to buff clayey material.	16		542	
Gypsum, fibrous, banded with greenish grey shale.	2		544	
Gypsum, grey, mottled, becoming coarser and blue with depth.	5		549	
Gypsum, with shale impurities, folded bands, amount of gypsum decreases with depth.	5		554	
Gypsum, pure, light blue, banded with anhydrite, pure 6" band of blue crystalline gypsum at 550', impure gypsum at 551'	5		559	
Gypsum with calcareous brown shale.	2		561	
Gypsum, mottled, with shale.	2		563	
Gypsum and anhydrite, fine grained below 565'; grading from grey to buff at 572'	17		580	
Anhydrite, bluish, hard, containing bands of gypsum.	10		590	
Dolomite, buff, massive, with gypsum.	4		594	
Anhydrite, white to grey, crystalline, with gypsum bands up to 4" thick.	2	6	596	6
Dolomite, buff to brown massive, with lenses of gypsum. Dolomite changes to impure dolomitic limestone at 598½' for 6 inches.	2	6	599	

	Thickness		Depth	
	Ft.	In.	Ft.	In.
Dolomite, brown massive with powdery gypsum for 2 feet. Small gypsum lenses at 606, 609 and 618'; impure shaley and calcarecus band at 625'.	29		628	
Dolomite, buff to grey with depth, massive with selenite at 632, 633 and 640 and salt pits.	15		643	
Dolomite, buff, massive, with salt cavities and blue selenite lenses. Impure calcareous shale band at 648'.	7		650	
Dolomite, broken and fragmental, slickensided, with gypsum.	1		651	
Dolomite, grey to brown, pitted with irregular selenite lenses.	15		666	
Dolomite, brown, irregularly banded, with black stains and salt cavities.	8		674	
Dolomite, grey, calcareous with a 6" band of mottled gypsum and anhydrite at 676'.	6		680	
Dolomite, grey, with gypsum bands and stringers.	5		685	
Dolomite, grey, uneven texture with 1" gypsum inclusions.	1		686	
Dolomite, grey brown to grey with depth, massive. Salt cavities and some gypsum.	16		702	
Dolomite, grey, thin bedded, gypsum layers and lenses.	2		704	
Dolomite, grey, thin bedded, pitted, salt crystals.	5		709	
Calcium carbonate, yellow, porous.		2	709	2
Dolomite, uneven texture, fragmental containing salt cavities, selenite and white powdery gypsum.	4	10	714	
Dolomite, grey to dark impure type with depth, with some gypsum at 724, pronounced dip.	11	6	725	6
Calcium carbonate, yellow porous as at 709.		6	726	
Gypsum and anhydrite, thin bedded, lensey, also dolomite, containing mottled gypsum.	7		733	
Dolomite, buff, brittle, containing some gypsum in mottled form.	4		737	
Gypsum, pure white 2" band.		2	737	2
Dolomite, grey with anhydrite and lenses of gypsum.	3	10	741	
Dolomite, thin bedded and some anhydrite, and thin irregular bands of gypsum.	5		746	
Dolomite, buff colored	2		748	

	Thickness Ft.	Thickness In.	Depth Ft.	Depth In.
Anhydrite and gypsum, massive.	6		754	
Dolomite, buff to light grey with depth, massive, with selenite lenses.	12		766	
Shale, bluish, thin bedded with fibrous gypsum bands.		6	766	6
Gypsum and anhydrite, thin bedded.	7	6	774	
Shale, grey, calcareous.	1		775	
Gypsum and anhydrite, interbedded.	1		776	
Gypsum and anhydrite, grey, mottled, with some gypsum stringers, impure calcareous type at 780'.	4		780	
Gypsum with angular quartz veins.	2		782	

A P P E N D I X I

The Development of the Gypsum Industry in Canada.

"The gypsum industry is one of the oldest mineral industries in Canada, gypsum having been produced for over 150 years".* Since that time the gypsum industry has shown a yearly production from some part of the country despite the setbacks it has met. The early production from Nova Scotia was followed by production from New Brunswick in 1816, Ontario in 1822, Manitoba in 1901 and British Columbia because a gypsum producer in 1926.

The production of gypsum in Canada increased steadily from year to year until 1913. In the ensuing war period the gypsum industry showed a marked decline but in the following ten year period; i. e.,from 1919 to 1928, the gypsum industry on the whole has shown a rapid increase in production. Production figures for 1931 and 1932 show a decrease of approximately one-third and two-thirds respectively from those of 1928 but has shown an increase in the past year.

The gypsum discovery in Nova Scotia has the distinction of being the first in North America. Its discovery was followed by discoveries in 1792 in New York, 1923 in Michigan and 1849 in Ohio.

Nova Scotia and Ontario were the principal producers in Canada during the first half of the ninteenth century. Production

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*Cole, L. H.: Mines Branch Rept. No. 714, p. 122.

from New Brunswick in small quantities is known to have antidated the year 1847. Production was really established on a commercial scale in 1854.

Due to its accessibility to marine transportation the gypsum industry in Nova Scotia expanded more rapidly than did that of Ontario. The Ontario deposits, of necessity, had to depend on its local market. The industry is, however, now well established and represents an important feature in Ontario's mineral output.

The year 1901 marked the establishment of the gypsum industry in Manitoba. It has shown a steady yearly increase in production since that time up to the depression period. The recent opening and operation of the Amaranth deposits, 1930, has added measureably to Manitoba's output which previously came chiefly from Gypsumville.

Although gypsum was discovered in British Columbia as early as 1894, production was not established until 1911. From this time till 1926 production was spasmodic. Regular production was established in 1926 from the Falkland and Mayook deposits. At the present time the Falkland deposits represent the only steady producer.

Up to the present time Alberta has not entered into the commercial production of gypsum. The exploitation of the Peace River deposits can only be carried out when transportation facilities become more favorable. The recent activities in the Lake Athabaska

gold field and the proposed development of the McMurray bituminous sands may in short time have the effect of stimulating an interest in the Peace River gypsum deposits. Such a development would more than likely occur subsequent to a development of the salt industry in the district and would depend on improvements in transportation facilites brought about by the exploitation of other minerals in the area.

APPENDIX II

The Economic Importance of Gypsum in Canada.

The gypsum industry of Canada represents one of the more important non-metallic mineral industries of the country. The gypsum itself rates very high in quality. Although the major part is used in the manufacture of structural materials the white rock variety found in Nova Scotia, New Brunswick and Ontario is used in many of the fine arts.

In world production figures of gypsum Canada stands in third place. As yet the export trade in crude gypsum is a major feature of the industry. The internal consumption is however steadily increasing and now represents a value of 50 percent of the total gypsum production of the country.

A detailed account of gypsum statistics has been presented by Cole. It will be sufficient for our purposes to present such statistics in general outline. The following table represents in general the story of the value of the gypsum industry to Canada during its development:

Year	Long Tons	Value
1909	473,129	$ 809,632
1913	636,370	1,447,739
1918	152,287	823.006
1922	559,265	2,160,898
1928	1,205,846	3.622,007

The gypsum industry showed a general yearly increase in production up to the year 1913. Due to war conditions the

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*Cole, L. H.: Mines Branch Rept. No. 714, p. 122.

industry showed a marked decline during the next five years, reaching its low point in production in 1918. With the exception of two minor recesses in 1921 and 1923 the industry showed rapid growth up to the year 1928.

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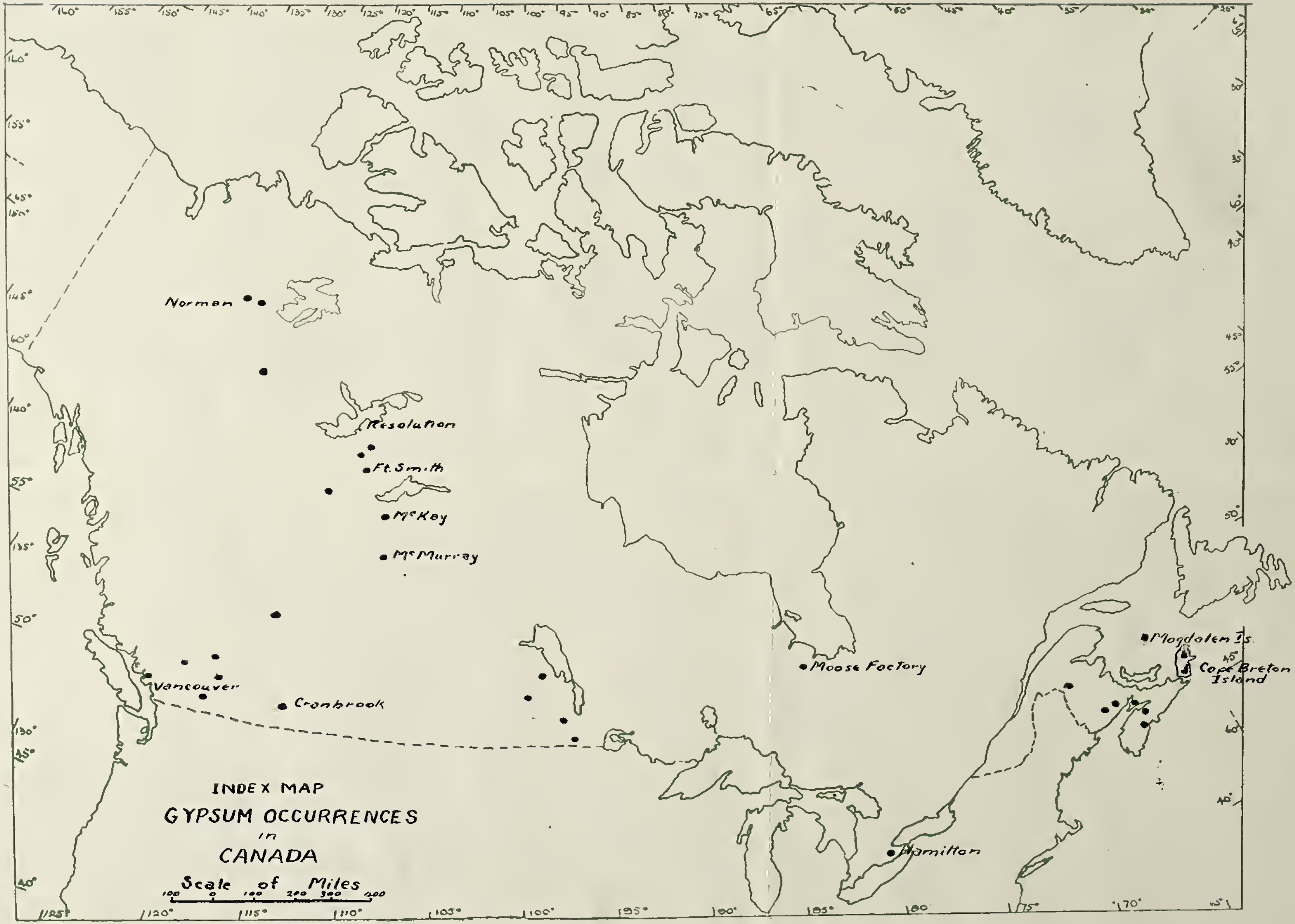

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GYPSUM OCCURRENCES
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